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NATIONAL DEFENSE RESEARCH COMMITTEE

of

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR METALLURGY DIVISION

Final Report

on

HEAT-RESISTANT ALLOYS FOR ORDNANCE MATERIEL AND AIRCRAFT AND NAVAL ENGINE PARTS (N-102): PART I - HEAT-RESISTANT ALLOYS OF THE 21% Cr: 9% Ni TYPE

by

HOWARD S. AVERY AND EARNSHAW COOK
AMERICAN BRAKE SHOE COMPANY

OSRD No.______

Serial No. M-496

Copy No. 16

June 29, 1945

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June 29, 1945

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Final Report on "Heat-resistant Alloys for Ordnance Materiel and Aircraft and Naval Engine Parts (N-102): Part I - Heat-resistant Alloys of the 21% Cr: 9% Ni Type".

The attached final report submitted by Earnshaw Cook, Technical Representative on NDRC Research Project NRC-84A, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report presents the results of an investigation of the physical properties at elevated temperatures of commercially available alloys of the 21% Chromium: 9% Nickel type.

This project was financed by the American Brake Shoe Company and was carried out as a correlation project under the supervision and direction of the War Metallurgy Committee. I recommend acceptance as a satisfactory final report on a phase of the work done on this project.

Respectfully submitted,

Clyde Williams

Clyde Williams, Chief
War Metallurgy Division, NDRC

Enclosure

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PREFACE

This report is pertinent to the problems designated by the Office of the Coordinator of Research and Development, Navy Department, as N-102, and to the project designated by the War Metallurgy Committee as NDRC Research Project NRC-84A.

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SUMMARY REPORT

for

NATIONAL RESEARCH COUNCIL PROJECT 84-A

Heat Resistant Alloys for Ordnance Materiel and Aircraft and Naval Engine Parts: Properties of 21%Cr:9%Ni Type Alloys

Departmental Report No. 7-M-92

Case Report No. 263-2

by

Howard S. Avery
Research Metallurgist

Mahwah, New Jersey

March 6, 1945

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SUMMARY

This report concerns the engineering properties, not previously known, of a commercially available heat resistant alloy. The generally accessible data on 18%Cr:8%Ni stainless steels refer chiefly to the low carbon compositions, whose apparent creep strength is lower than that of the higher carbon cast alloys usually employed for elevated temperature service. The present study has delineated materials that will substitute below 1600°F for the widely used 26%Cr:12%Ni grade.

To improve oxidation resistance, the chromium level of 18:8 has been raised to 19-22%. To provide austenite stabilization, the nickel range has been set at 8.5 - 10.5% and 0.07 - 0.11% nitrogen included. This austenitizing balance is justified by principles that were developed during research on the 26%Cr:12%Ni alloy.

The latter is susceptible to embrittlement from carbide precipitation and from development of the sigma phase at and below 1600°F. Compositions of this type, quite strong and ductile at 1800°F, may thus become seriously brittle in the range from 1200-1600°F. Since the compound FeCr is the basis of the sigma phase, its development is theoretically favored by high chromium content. Studies of the microstructure of the 21%Cr:9%Ni grade have indicated that sigma may develop, but that it appears in smaller quantities which have less embrittling effect than in 26%Cr:12%Ni type.

The upper limit of application is probably established by hot gas corrosion. Industrial experience has justified the employment of 21%Cr: 9%Ni up to 1600°F in oxidizing atmospheres.

A commercial foundry range as above has been surveyed to determine the most significant mechanical properties. The cast alloys exhibit about 90000 psi tensile strength and 30% elongation. After aging for 24 hours at 1400°F, which is a treatment frequently applied to 26%Cr:12%Ni, tensile strength usually rises and elongation may fall to below 20%. These room temperature properties are ample for most industrial applications.

Stress-strain-rupture and creep tests have established limiting creep stress values and ductility characteristics at 1200°F, 1400°F, and 1600°F of the range from 0.25 - 0.35% carbon, 19.3% - 22.3% chromium, and 7.7 - 10.5% nickel. They also permit tentative estimates of life expectancy. Proper design strengths may be inferred from these data, which justify the conclusion that the 21%Cr:9%Ni grade (if compositional control is adequate) may be substituted for 26%Cr:12%Ni up to a temperature of 1600°F without change of design stresses. Less embrittlement at service temperatures is an additional advantage.

The chief value of this material is in the heat resistant alloy field. Its usefulness is not confined to elevated temperature service, however. The stable austenites are substantially non-magnetic, having a permeability of about 1.003 in the as-cast state. They are corrosion resistant and machinable. This combination of properties makes them also suitable for applications that require a strong, tough, machinable, non-corrosive and non-magnetic metal.

HEAT RESISTANT ALLOYS OF THE 21%Cr:9%Ni TYPE

Introduction

This project was established in April 1944, as NDRC Correlation Project NRC-84A with the following general objectives:

1. To determine the elevated temperature characteristics of heat-resisting alloys used in national defense applications.

2. To conduct experiments directed toward the improvement of these alloys where present properties are inadequate.

3. To clarify the possibilities of substitutions that will permit savings in strategic alloying elements.

4. To adapt knowledge of the heat-resistant alloys to the specialized applications that have developed because of the war.

The project is being financed by the American Brake Shoe Company, and is being conducted under the general supervision of the War Metallurgy Committee. This report is the initial report submitted on the project.

This paper is essentially a description of the engineering properties of a commercially available heat resistant alloy whose merits for service in suitable temperature ranges have been neglected because of inadequate technical data.

There is a definite field for a strong and tough intermediate temperature alloy. Up to 1200°F ferritic steels and heat resistant cast irons are widely applied. Where plasticity is essential, steels must be used. The irons exhibit some ductility above 900°F, but they are seldom able to survive sudden thermal or mechanical stresses that exceed their elastic strength. Ferritic steels, of which 5%Cr:1/2%Mo type is an example, are thus preferred for service up to approximately 1200°F. Above this they lose strength rapidly and the proximity of their transformation ranges is undesirable. Austenitic alloys are indicated instead because of their greater strength and stability.

The alloy grade containing 24-28%Cr and 10-14%Ni (A.C.I. Type HH) is most often selected for the high temperature ranges. In the absense of carburizing conditions, which cause it to embrittle rapidly, it is probably the most useful commercial alloy for carrying high stresses at uniform temperatures up to 2100°F.

Several years ago the Alloy Casting Institute received a request from several oil refining companies for a specification, lower in strategic elements, that could replace the 26%Cr:12%Ni grade below 1600°F, the lower limit for authorized applications by the War Production Board. The Battelle Memorial Institute, under the sponsorship of the Alloy Casting Institute, conducted an extensive research program that resulted in an alloy of 12%Cr, 2%Si, 6%Ni, and 6%Mn, described before the A.S.M. in 1943.(1) Test data for this material indicated that 1400°F was probably the upper limit at which it could be employed satisfactorily. It is not considered an adequate substitute for 26%Cr:12%Ni between 1400°F and 1600°F.

For some years an upward revision of the familiar 18%C:8%Ni grade has been manufactured for intermediate temperature service to the specification* of:

C%	Mn%	Si%	Ni%	Cr%
0.25	0.25	0.50	7.5	19.0
0.35	1.75	1.75	10.5	22.0

Field experience established that it could be employed up to 1600°F without excessive surface oxidation. Design stresses were customarily low as it was assumed to be similar to 18%Cr:8%Ni in strength. While somewhat lower in cost than the widely used 26%Cr:12%Ni grade, it was generally considered inferior because of its lower alloy content, and consequently 26%Cr:12%Ni has many times been specified, despite the additional expense, for the ranges below 1600°F where its superior oxidation resistance is not required. It is noteworthy that this assumed inferiority of 21%Cr:9%Ni has never been proved at temperatures where its surface stability is adequate.

Alloy substitution in engineering designs for elevated temperature service requires a knowledge of creep strength. A survey of the literature revealed a number of publications dealing with 18%Cr:8%Ni, several of which detail limiting creep stress values over the range from 900°F to 1500°F. They generally relate to low carbon compositions that are more typical of corrosion resistant alloys. Little information on the carbon ranges used for high temperature service could be found. The status encountered is summarized in Table 1 and in Figure 1, which also shows typical properties obtained in this investigation. Most of the published test data result from short-time elevated temperature tension tests. Among those available, the compilations of H.D. Newell (2)(3) are noteworthy. Unfortunately, short-time tests do not provide an adequate basis for design.

Consideration of the evidence indicated that the 21%Cr:9%Ni type might have a wider range of usefulness and that reported properties of 18%Cr:8%Ni were not necessarily characteristic of its somewhat different composition range. Clarification of this would require a program of creep testing to delineate the properties of the specification for elevated temperature service. The necessary work was initiated by the American Brake Shoe Company Metallurgical Laboratory in 1942 and is reported herein.

Procedure

To survey a chemical analysis range, within which six elements** operate as variables, may entail the production and testing of many compositions. Fortunately, experience(4) with the 26%Cr:12%Ni type has clarified the role of

*Employed by the American Manganese Steel Division of the American Brake Shoe Company.

**The influence of these elements has been the subject of considerable unpublished research, which was utilized as the basis for selecting the compositions included in this report.

THE AMERICAN BRAKE SHOE AND FOUNDRY CO.

METALLURGICAL DEPARTMENT

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Mahwah, N. J. September 22, 1942

Table 1

Creep Strength of 18%Cr:8%Ni Alloys

Source	Condition	C%	Mn%	Si%	Ni%	Cr%	V%	Temp. °F.	L.C.S. 1% El.-10000 Hrs. P.S.I.
Metal Progress	Wrought	.10	.50mx	.50mx	8/10	17/19		1000	17000
								1200	7000
								1350	3000
								1500	850
Babcock & Wilcox	Wrought	.08	2.0mx	.75mx	8/11	18/20		900	24000
								1000	18300
								1100	11550
								1200	6600
								1300	2500
		.14	.45	.32	8.2	18.2	.13	1200	9000
Timken	Wrought	.07	.20/70	.75mx	8/15	17/19		1000	18000
								1100	13200
								1200	8200
								1500	2850
A.S.T.M.(Cross)	Wrought	.07	.50	.65	9.56	18.21		1000	20000
								1200	8000
	Cast	"	"	"	"	"		1000	14500
								1200	8500
A.S.T.M.(Cross)	Wrought	.13	.47	.58	9.67	18.50		1000	24800
								1100	17000
								1200	10500
	Cast	"	"	"	"	"		1000	22500
								1100	17000
								1200	9000

These data are plotted in Figure 1.

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each element. Carbon, nickel, and nitrogen stabilize austenite and usually contribute strength. Chromium and silicon tend to produce ferrite and concurrently to reduce strength, generally with an increase in ductility. They also promote the development of the brittle, undesirable sigma phase under some conditions, thereby lowering ductility. Manganese is relatively neutral and is not considered a potent factor.

The five important elements operate together to produce a phase formation tendency herein termed "the austenite balance". If low, considerable ferrite will be present at some temperatures; if high, only carbides and austenite are expected. The ferromagnetic properties of ferrite permit its detection and estimation by magnetic permeability measurements, which thus become indices of the austenite balance until ferrite is completely suppressed(5). A correlation of permeability with creep strength has been reported for 26%Cr:12%Ni alloys.(4)

By selecting a composition containing minimum carbon, nitrogen, and nickel, together with maximum chromium and silicon, the low strength - high ductility extremity of the chemical range is expected. Similarly, the reverse combination should produce minimum ductility and maximum strength. A mid-range alloy, to represent average properties, is also desirable. Production and testing of three analyses, as listed in Table 2 were thus projected. Manganese, not being considered a significant variable, was held constant.

Table 2

Compositions Specified for Exploration

	Chemical Analysis						Austenite	
	C%	Mn%	Si%	Ni%	Cr%	N%	Balance*	Properties Expected
(1)	0.25	0.90	1.75	7.5	22.0	.05	Minimum	Max. ductility; min. strength
(2)	0.30	0.90	1.15	9.0	20.5	.08	Mid-range	Average properties
(3)	0.35	0.90	0.50	10.5	19.0	.10	Maximum	Min. ductility; max. strength

*The use of minimum and maximum under this heading does not imply that the included range covers wholly austenitic alloys. This status was not clarified until magnetic test data, as summarized in Table 9, page 20, became available.

After it became apparent that the heat with the minimum austenite balance was quite ferritic, and considerably weaker than the other two, a fourth composition was added to represent the low strength extremity of a narrower specification range. Detailed analyses of the heats appear in Table 3.

The alloys were melted in an induction furnace and cast in headed 1-inch diameter bars, as detailed in Figure 2. This practice was developed to obtain satisfactory freedom from microscopic shrinkage defects that would invalidate quantitative comparisons of mechanical properties.

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Table 1 **G-263-2**

Room Temperature Properties of 21%Cr:9%Ni Alloys

Heat No.	Chemical Composition C%	Mn%	Si%	Cr%	Ni%	N%	As Cast Magnetic Perm. B-24	Yield Str. PSI	Tensile Str. PSI	Elong. % in 2"	Red. Area %	Hardness BHN	Heat Treatment °F.-Hours-Cooling
KF129	.25	.96	1.72	22.3	7.7	.07	1.60	47500	95000	27.5	26.5	181	As Cast
								40000	98500	28.5	25.1	190	1400-24-Fce.
								42500	98250	29.5	26.8	190	" " "
KH39	.25	.85	.92	21.2	8.7	.09	1.04	41500	73250	47.2	39.2	167	As Cast
								52500	100250	30.0	30.8	176	1400-24-Fce.
								57500	99750	34.5	34.1	176	" " "
KF130	.28	.96	1.15	20.8	9.1	.09	1.00	45000	91750	39.0	37.9	163	As Cast
								51500	107250	25.0	26.8	203	1400-24-Fce.
								55000	107250	23.0	22.0	199	" " "
KF131	.34	.92	.48	19.3	10.5	.11	1.00	49000	92750	32.0	37.9	167	As Cast
								51500	100500	18.0	19.5	210	1400-24-Fce.

Properties of Representative 26%Cr:12%Ni Alloys for Comparison

Heat No.	C%	Mn%	Si%	Cr%	Ni%	N%	As Cast Magnetic Perm. B-24	Yield Str. PSI	Tensile Str. PSI	Elong. % in 2"	Red. Area %	Hardness BHN	Heat Treatment °F.-Hours-Cooling
KH121	.29	.52	1.07	26.2	11.6	.14		45000	91000	34.0	37.6	179	As Cast
								45000	94000	17.5	23.7	202	1400-24-Fce.
									94500	18.5	22.3	202	" " "
KH150	.31	.51	.53	26.8	10.6	.14		45000	91500	25.5	34.1	196	As Cast
								44000	94000	19.5	26.1	192	1400-24-Fce.
								47000	95000	23.5	29.8		" " "
KH63	.32	.53	.50	26.2	11.5	.07		42500	86250	28.5	30.8	179	1400-24-Fce.
								45000	85250	28.0	37.6	179	" " "
GH518	.32	.46	.45	25.9	11.5	.16	1.00	49000	82000	17.5	23.7	156	As Cast
								50500	86000	6.5	7.0	196	1400-24-Fce.
								50000	86500	6.5	7.0	207	" " "
KH157	.32	.49	.63	23.9	13.2	.09	1.00	45000	94000	32.0	27.2	166	As Cast
								42500	101000	11.5	11.1	207	1400-24-Fce.
								45000	100000	11.0	10.0	207	" " "

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Testing has followed A.S.T.M. procedure in general. The yield strengths, which are based on observation of a hydraulic dial gauge, approximate values based on 0.2% permanent set. Elevated temperature tests have followed the technique described in A.I.M.E. Technical Publications(6)(4) No. 1443-C and No. 1480. Properties of a comprehensively tested 26%Cr:12%Ni alloy described in these publications have been included in the Appendix for comparisons. (Table 11 and Figure 11).

Room Temperature Mechanical Properties

As-cast properties have little relationship to service performance or to design calculations for heat resistant alloys. Since they are occasionally requested by engineers, however, the results of a single test from each heat are included in Table 3.

The 21%Cr:9%Ni grade has been specified for intermediate temperature service in oil refinery castings. As such, it is purchased under specifications that include tension tests after aging for 24 hours at 1400°F; a minimum elongation of 9.0% is usually required. As shown in Table 3 these alloys exceed this minimum by a wide margin.

Loss of ductility after this aging treatment is usually indicative of carbide precipitation. The data suggest that this grade does not become seriously brittle. The adverse effect of carbon upon ductility may be inferred from the trend above, however. The virtue of these tests after aging as an acceptance procedure is controversial. It is doubtful if they can consistently predict behavior after long periods under stress. The information on residual ductility after creep testing, which is included later in this report, is much more valuable.

Elevated Temperature Properties

Stress-strain-rupture tests are an excellent measure of elevated temperature ductility, permit an estimate of maximum life expectancy, facilitate the selection of loads for 1000 hour creep tests, and in this investigation provided a reasonably accurate prediction of limiting creep strength in most cases. They were chosen in preference to the conventional short time tension test because they correlate with, as well as supplement, long term creep tests. This survey includes tests at two loads for each of three temperatures, which are tabulated in the appendix. The ductility characteristics, as portrayed by elongation at fracture, are summarized in Table 4, which also lists four, 26%Cr:12%Ni alloys for comparison.

Table 4

Comparative Elevated Temperature Ductility

Heat No.	Composition C%	Cr%	Ni%	Elongation During Stress-Rupture Tests - % in 2" 1200°F 45000 PSI	1200°F 35000 PSI	1400°F 20000 PSI	1400°F 15000 PSI	1600°F 10000 PSI	1600°F 8000 PSI	1800°F 6000 PSI	1800°F 4000 PSI
XJ129	.25	22.3	7.7	-	22	44	49	50	-	-	-
XK39	.25	21.2	8.7	16	9	10	9	15	10	-	-
XJ130	.28	20.8	9.1	23	5	6	6	-	7	-	-
XJ131	.34	19.3	10.5	10	6	4	3	-	13	-	-
XG121	.29	26.2	11.6	-	-	22	13	-	-	19	-
XG150	.31	26.8	10.6	-	-	16	9			41	36
CH518	.32	25.9	11.5	-	-	6	3	-	4	12	-
XG157	.32	23.9	13.2	-	-	4	3	-	-	9	5

The tendency for ductility to decrease as the austenite stabilizing balance increases is apparent. That this is not attributable to the effect of carbon alone is demonstrated by a comparison of XJ-129 and XK-39, which both contain 0.25%C but differ in the austenite balance of other elements. A similar trend appears for the 26%Cr:12%Ni compositions, as would be expected.

The downward trend of ductility as loads decrease and fracture times increase is noteworthy. This is a frequently observed characteristic of austenitic structures. It demands caution when interpreting the data from short tests. Otherwise ductile alloys may fracture after long periods under low stress with less than 1% elongation. From Table 4 it may be possible to infer the behavior of a material under rapidly imposed overloads, but the values shown should not be expected at the limiting creep stress.*

Fracture times are presented in Table 5. The heat with the minimum austenite balance (XJ-129) exhibits significantly shorter life than do the other three under the same loads. This is a result of a comparatively large proportion of ferrite in its constitution, which will be demonstrated later by photomicrographs and magnetic test data. The more stably austenitic compositions have a group similarity, though minor trends are evident. At 1200°F life decreases with the rise of the austenite balance; at 1600°F the reverse is true. An intermediate behavior appears at 1400°F with a peak for the mid-range alloy (XJ-130). In comparison with 26%Cr:12%Ni the average fracture time is shorter, but the values are of the same order of magnitude.

*This will be abbreviated as L.C.S. hereafter, and denotes the stress that will produce a minimum or secondary stage elongation rate no greater than 0.0001% per hour, which is equivalent to 1% in 10000 hours.

Table 5

Comparative Elevated Temperature Life

Heat No.	Composition C%	Cr%	Ni%	Stress-Rupture Test Fracture Time - Hours: 1200°F 45000 PSI	1200°F 35000 PSI	1400°F 20000 PSI	1400°F 15000 PSI	1600°F 10000 PSI	1600°F 8000 PSI	1800°F 6000 PSI	1800°F 4000 PSI
XJ129	.25	22.3	7.7	-	2.8	3.5	20.0	4.0	-	-	-
XK39	.25	21.2	8.7	2.3	25.4	6.2	37.2	5.4	17.6	-	-
XJ130	.28	20.8	9.1	1.3	19.1	7.8	63.9	-	46.0	-	-
XJ131	.34	19.3	10.5	0.6	14.2	6.4	29.8	-	32.5		
XG121	.29	26.2	11.6	-	-	13.0	86.1	-	-	9.5	-
XG150	.31	26.8	10.6	-	-	6.9	41.9	-	-	4.8	43.8
CH518	.32	25.9	11.5	-	-	13.9	60.3	-	41.4	16.6	-
XG157	.32	23.9	13.2	-	-	15.5	102.8	-	-	13.4	166.9

Stress-strain-rupture tests are actually short term creep tests continued to fracture. As such, they yield minimum elongation rates characteristic of the secondary stage of creep. These, logarithmically plotted with analogous rates from 1000 hour creep tests, portray the minimum creep rates associated with a wide range of stresses. By this combination it has been possible to obtain an adequate determination of L.C.S. values with only one long time creep test of each composition at each temperature. Time-elongation curves for these appear in the appendix.

It is convenient to plot fracture times on the same graph with creep rates, as in Figures 12, 13, 14, and 15 (Appendix). While extrapolated fracture times must be employed with extreme caution, it is thus possible to estimate the time before rupture at any stress or any minimum creep rate. Table 6 is a summary of the L.C.S. and suggested design stress values for each heat, together with the associated tentative fracture times obtained by extrapolation. A comprehensively tested 26%Cr:12%Ni alloy is included for comparison.

It is customary to use 50% of the L.C.S. (for 0.0001% per hour or 1% in 10000 hours) as a safe tensile working stress. This is a desirable practice as the stronger alloys may have poor life expectancy at their L.C.S. Suggested design strengths of the 21%Cr:9%Ni compositions here reported range from 1500 to 3200 psi at 1400°F. Because of its greater plasticity, the low strength alloy (XJ-129) may be appropriate for use at its L.C.S. of 3100 psi, while the low ductility material (XJ-131, with 6000 psi L.C.S.) obviously is not. The design stress of 3050 psi, established by the 26%Cr:12%Ni grade, is probably suitable for all of the four compositions in Table 6. This status would be similar to that of the current industrial 26%Cr:12%Ni alloys, many heats of which are partially ferritic and weaker than the one referred to above, which is wholly austenitic. Such an assumption would permit the utilization of a wide foundry specification.

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Table 6

C-263-2

Limiting Creep Stresses, Suggested Design Stresses, and Maximum Life Expectancy of 21%Cr:9%Ni Heat Resistant Alloys

Heat No.	Magnetic Perm. As Cast H=24	--Chemical Composition--- C%	Mn%	Si%	Cr%	Ni%	N%	Temperature °F.	Limiting Creep Stress* PSI	Maximum Life** Expectancy Years	Suggested Design Stress PSI	Maximum Life** Expectancy Years
XJ129	1.60	.25	.96	1.72	22.3	7.7	.07	1200	8600	15+	4300	15+
								1400	3200	15+	1600	15+
								1600	1700	15+	850	15+
XK39	1.04	.25	.85	.92	21.2	8.7	.09	1200	14500	15+	7250	15+
								1400	5600	1.7	2800	15+
								1600	3100	0.34	1550	15+
XJ130	1.00	.28	.96	1.15	20.8	9.1	.09	1200	14500	15+	7250	15+
								1400	6400	3.4	3200	15+
								1600	3300	3.4	1650	15+
XJ131	1.00	.34	.92	.48	19.3	10.5	.11	1200	14500	15+	7250	15+
								1400	6000	0.48	3000	15+
								1600	3000	0.34	1500	7.6

A 26%Cr:12%Ni Alloy for Comparison

Heat No.	Magnetic Perm. As Cast H=24	C%	Mn%	Si%	Cr%	Ni%	N%	Temperature °F.	Limiting Creep Stress* PSI	Maximum Life** Expectancy Years	Suggested Design Stress PSI	Maximum Life** Expectancy Years
[illegible]	1.00	.32	.46	.45	25.9	11.5	.16	1400	6100	0.7	3050	15+
								1600	3200	0.6	1600	15+
								1800	1750	2.5	875	15+
								2000	800	1.4	400	15+

*Stress for minimum elongation rate of 0.0001% per hour

**As these data are based on only two short term tests they afe not suitable for design purposes, but are included to permit comparisons between the alloys.

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AMERICAN BRAKE SHOE COMPANY

METALLURGICAL DEPARTMENT

Mahwah, N. J. February 5, 1945

Table 7 G-263

Residual Mechanical Properties After Creep Testing 21%Cr:9%Ni Alloys

Heat No.:	XJ-129	XK-39	XJ-130	XJ-131
	Chemical Analysis			
C%	.25	.25	.28	.34
Mn%	.96	.85	.96	.92
Si%	1.72	.92	1.15	.48
Ni%	7.68	8.65	9.10	10.53
Cr%	22.33	21.20	20.80	19.25
N%	.067	.085	.086	.108

Creep Tested at 1200°F.

	XJ-129	XK-39	XJ-130	XJ-131
Creep Test Stress - P.S.I.	10000	15000	15000	15000
Duration - Hrs.	1004.(d)	1292.(d)	1004.(d)	1001.(d)
Yield Strength - P.S.I.	65000	50000	75000	56250
Tensile Strength - P.S.I.	93375	100500	97000	90000
Elongation - %	20.0	16.0	12.0	5.0
R.A. - %	20.2	7.4	14.2	8.2

Creep Tested at 1400°F.

	XJ-129	XK-39	XJ-130	XJ-131
Creep Test Stress - P.S.I.	3000	6000	6000	6000
Duration - Hrs.	1002.(d)	1004.(d)	1003.(d)	1005.(d)
Yield Strength - P.S.I.	57500	45000	70000	-
Tensile Strength - P.S.I.	88850	92750	106750	38000*
Elongation - %	15.0	15.0	20.0	2.0*
R.A. - %	14.1	16.1	18.4	1.1*

Creep Tested at 1600°F.

	XJ-129	XK-39	XJ-130	XJ-131
Creep Test Stress - P.S.I.	1500	3000	3000	3000
Duration - Hrs.	1004.(d)	1003.(d)	1003.(d)	1001.(d)
Yield Strength - P.S.I.	55000	70000	35750	50000
Tensile Strength - P.S.I.	92250	87250	88250	77750*
Elongation - %	20.5	14.0	10.0	6.5*
R.A. - %	18.8	14.5	8.1	10.6*

*Low residual strength and ductility attributed to structural damage.

(d) Discontinued before fracture.

For critical applications it would be desirable to eliminate weak, ferritic compositions such as XJ-129 and to base foundry specifications on a range within which L.C.S. values are approximately the same. This is possible by using XK-39 and XK-131 as extremes. The suggested limits are:

C%	Mn%	Si%	Ni%	Cr%	N%
0.25	0.25	0.50	8.5	19.0	0.09
0.35	1.75	1.00	10.5	21.0	0.11

Compositions entirely within this range are expected to be substantially, if not wholly, austenitic. Since many analyses slightly outside this range would be acceptable they should not be excluded arbitrarily. Provision for acceptance, if magnetic analysis indicates a satisfactory austenite balance, should be included.

Stability at Elevated Temperatures

Phase changes controlled by the nature of the alloy and structural damage resulting from applied stress contribute to reduced stability at elevated temperatures. If compositions in the range under discussion are entirely austenitic, the major constitutional changes are associated with carbide solution and precipitation. With carbon in solution, the matrix is relatively ductile. Extended exposure in the lower temperature ranges causes reprecipitation in a finely dispersed form, with decreased ductility and greater strength as a result. This carbide precipitation provides a serious limitation to the applications of the 26%Cr:12%Ni grade. The room temperature tensile tests after extended creep testing, as detailed in Table 7, suggest that the 21%Cr:9%Ni alloy has greater resistance to such embrittlement. This factor justifies its substitution for the higher alloy type. (Comparable data on 26%Cr:12%Ni appear in Table 11 of the appendix.)

Other phase changes may also occur. Exposure in the range from 1200°F to 1600°F may cause appreciable ferrite to develop if the austenite balance is too low. This ferrite, which may be detected by magnetic analysis or by microscopic examination, is considerably weaker than the austenite and its appearance, as in heat XJ-129, is associated with low strength and high ductility.

There is microscopic evidence that the sigma phase has appeared under some conditions. It is weak, brittle, and undesirable. It sharply limits the usefulness of some of the 26%Cr:12%Ni alloys; but 21%Cr:9%Ni specimens in which it has been detected seem to have suffered little embrittlement because of its presence. The residual elongation after creep testing of those specimens in which sigma has been tentatively identified is higher in general than that of 26%Cr:12%Ni alloys in which it is absent. This observation is also favorable to the use of 21%Cr:9%Ni between 1200°F and 1600°F.

A more obscure form of instability is associated with over-stressing. This perhaps takes the form of incipient cracking under load. When it occurs, the residual ductility is below the normal expectancy. In this group, the tension test on the high strength, low ductility extreme (XJ-131) at 1400°F, suggests that structural damage has occurred. The low tensile strength associated with this test is confirmatory. The specimen in question was loaded at approximately the limiting creep stress for 1005 hours. Obviously, this would not be a safe design load. If 50% of this, as a standard design stress, were employed, the life expectancy would probably be satisfactory. It is not unusual to encounter a similar loss of residual ductility and strength in the 26%Cr:12%Ni alloys, especially in the higher strength ranges. This is the only clear case that has been observed in the present investigation. The similar creep test at 1600°F suggests this mechanism but the higher residual tensile strength and elongation indicate that structural damage, if present, had not progressed seriously at the time the test was discontinued.

Hindered Contraction Characteristics

Self-imposed stresses from hindered expansion or contraction are an important source of structural damage. There is little doubt that they contribute to ultimate failure in many cases. They are generated by thermal shock, temperature gradients, and cyclic heating and cooling; their magnitude depending on elastic moduli, coefficients of thermal expansion, and environmental conditions. Evaluation of these factors and of the alloy characteristics that provide resistance to consequent damage is very difficult. The term "thermal fatigue" is sometimes applied to deterioration from these stresses; unfortunately there is no generally accepted method of dealing with it quantitatively.

If such thermal stresses considerably exceed the elastic properties of a metal, plastic flow will rapidly reduce them to the vicinity of a psuedo-yield strength. Thereafter, or for stresses below this, stress relief is slow and is dependent on the creep characteristics of the material. It is possible to determine experimentally the limits for rapid stress relief at various temperatures by means of hindered contraction tests.

Relief of stress by plastic deformation is expected to produce some change in an alloy. Compressive flow may not be harmful, but it is postulated with assurance that tensile deformation will exhaust to some extent the ductility reserve of a structural member. A salient difference between elongation that relieves hindered contraction stresses and the tensile elongation of conventional short time tests is the isothermal nature of the latter. A technique for integrating the effect of deformation over a wide range of temperaturesis desirable.

A test yet in the experimental stage has been employed to gain some knowledge of the qualities described above. By heating a specimen (16" x 7/8" diameter with a 1" x 0.505" diameter gaugelength) to 1800°F at the center in a tensile machine, applying a small load to remove any slack in the system, and then slowly cooling the test bar, the unrelieved stress characteristic of each temperature appears on the load indicator of the machine. As stress from contraction increases it normally produces some elongation of the specimen and some deflection of the testing machine crossheads. Removal of the latter complication is desirable. It has been accomplished by observing a deflection gaugethat connects the crossheads through fused silica rods and by operating the hydraulic controls of the machine to prevent or neutralize any specimen anchorage movement. Thus an approximately constant separation of the cool ends of the specimen is maintained.

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Table 8 **0-263-2**

Hindered Contraction Test Summary

Heat No.	C%	Cr%	Ni%	Cycle	1600°F.(2)	1400°F.	1200°F.	1000°F.	800°F.	600°F.	400°F.	200°F.	Total El.-%
	—Composition—				——Stress (PSI) Developed at Temperature by Cooling from 1800°F.(1)——								
XJ129	.25	22.3	7.7	1	5000	17000	26000	34000	42000	49000	55000	63000	8.0
				2	13000	22000	35000	46000	54000	62000	68000	75000	22.0
				3	12000	25000	38000	55000	64000	72000	77000	86000	38.0
				4	12000	24000	37000	52000	64000	73000	82000	90000	55.0
				5	9000	10000	30000	44000	57000	68000	Broke at 550°F.		68.0
XK39	.25	21.2	8.7	1	12000	24000	34000	43000	51000	58000	65000	72000	14.0
				2	12000	28000	40000	51000	60000	68000	74000	88000	27.0
				3	12000	28000	42000	53000	62000	70000	Broke at 520°F.		41.0
XJ130	.28	20.8	9.1	1	13000	24000	38000	48000	56000	63000	68000	77000	16.0
				2	16000	24000	36000	Broke at 1100°F.+			-	-	24.0
XJ131	.34	19.3	10.5	1	-	19000	32000	43000	52000	61000	68000	78000	9.0
				2	-	24000	37000	48000	57000	65000	73000	Broke	29.0
XM63	.32	26.2	11.5	1	11000	21000	30000	38000	44000	51000	56000	63000	11.2
XM63	(From 2000°F.)			1	12000	21000	31000	38000	45000	51000	55000	61000	21.0
XG157	.32	23.9	13.2	1	16000	28000	38000	47000	55000	63000	68000	72000	24.0
		(From 2000°F.)						Broke at 190°F.					

(1) Two tests, as indicated below, were cooled from 2000°F.

(2) As characteristic stresses are just being attained at this temperature, the two lowest values below may not be representative.

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Reasonable reproducibility of the test, which is not yet standardized, is provided by using the same furnace, anchorages, and specimen design each time. The initially applied load is a variable; the low values employed in this work are probably not optimum, as appreciable cooling is required before characteristic stresses appear.

The four alloys were subjected to this test. When room temperature was reached without fracture, the entire procedure was repeated. Two broke during the second cycle and one during the third; but the high ductility, low strength composition did not fail until near the end of the fifth cycle. The stresses developed by various temperatures are summarized in Table 8 and plotted on Figures 16, 17, 18, 19, 20, and 21. In parallel experiments it was found that an additional load, applied after arresting cooling at some temperature, quickly was reduced by flow to the value represented graphically but stress decrease thereafter was scarcely perceptible. Further changes, of course, could have been measured by more precise methods.

Listing the four alloys in order of decreasing austenite balance (Table 8), the relative strength at 200°F (for the first run in each case) is observed to follow this arrangement.

The capacity to absorb thermal stresses without fracture is currently considered an important indication of the hindered contraction test. While proof must await comparison with a thermal fatigue test of established validity, scrutiny of the technique discloses that it imposes a necessity to elongate without cracking over the entire range from service to room temperature. Incipient failure would be disclosed by a drop in stress (as for XJ-130). The five cycles before fracture of XJ-129, the weakest alloy, suggest that it has outstanding resistance to fracture and justify experimental applications to determine how this behavior can be exploited.

Interpretation of these data suggests that the more ductile alloys are less susceptible to fracture from thermal cause and, because of their lower strength, develop lower thermal stresses than do materials of higher strength. It follows that hindered contraction or temperature gradients are inherently more dangerous to the high-strength materials. Weaker, more ductile compositions, such as XJ-129, thus had a definite field of usefulness because, in appropriate sections, they can replace lighter castings of high strength to provide a greater factor of safety for installations where excessive thermal stresses cannot be avoided in design.

Oxidation Resistance

Industrial experience has approximately defined 1600°F as the upper limit of oxidation resistance of these alloys. Observation of the specimens after creep testing indicates that resistance to corrosion in normal oxidizing atmospheres at 1600°F is satisfactory.

While comprehensive hot gas corrosion tests have not yet been completed, two of the heats from this group were submitted, in the form of 1/2" x 1" x 2" blocks, to intermittent heating in oxidizing furnace gases at 1940°F. The fuel was natural gas with a low sulfur content. At the end of 1320 hours the 19% chromium alloy (XJ-131) was completely oxidized. The 22% chromium material (XJ-129) exhibited a surface loss of 0.02 inches. Further exposure for a total of 2240 hours raised the surface loss to 0.03" (0.06" in thickness) as compared with 0.02" for a 26%Cr:12%Ni standard. This rate of oxidation is tolerable, but of course the least resistant composition of a production range should govern the application, and obviously the 19% chromium level is not satisfactory at this high temperature.

Metallography

The matrix of these alloys is austenite. Complex chromium-iron carbides, ferrite, the sigma phase, non-metallic inclusions, and a lamellar constituent are also present under appropriate circumstances. The composition with maximum austenite stabilization exhibits only austenite, carbides, and the lamellar constituent whose nature is obscure. It is well illustrated in Figure 3. In the ferritic extremity all of the constituents except the lamellae have been tentatively identified. (Figures 4 and 5). The presence of ferrite is confirmed by magnetic analysis; sigma is recognized with less assurance, but the characteristically cracked areas of Figure 4 are typical. The finely dispersed carbides are present in all specimens; those exposed to the lower temperatures contain the largest amounts. (Figure 6). Characteristic microstructures after creep testing are exhibited in Figures 23 to 33, in the appendix.

Most of the carbides are found within the austenite grains. Pronounced grain boundaries are occasionally present, but they have not been correlated with low ductility as is sometimes possible.

The structures of these materials are revealed by etching first in 1:1 hydrochloric acid - which darkens ferrite and usually delineates the sigma phase - and subsequently staining with hot alkaline potassium ferricyanide (Murikami's reagent). The last treatment effectively identifies the carbides. The hydrochloric acid etchant usually, but not invariably, separates ferrite and sigma.

Magnetic Analysis

A close relationship between magnetic permeability and creep strength has been established for certain ranges of the 26%Cr:12%Ni alloy.(4) The probable error has appeared to be less than for other possible acceptance tests. The nature of the 21%Cr:9%Ni type is similar and a tabulation of permeability vs. creep strength (Table 9) confirms this. The four heats alone do not provide sufficient data to establish the relationship quantitatively. It is very probable that magnetic analysis could be used to reject low-strength compositions if a critical application were involved.

Table 9

Relation of Creep Strength and Magnetic Permeability 21%Cr:9%Ni Heat Resistant Alloys

Heat No.	XJ-129	XK-39	XJ-130	XJ-131
------Chemical Analysis------				
C%	.25	.25	.28	.34
Mn%	.96	.85	.96	.92
Si%	1.72	.92	1.15	.48
Ni%	7.68	8.65	9.10	10.53
Cr%	22.33	21.20	20.80	19.25
N%	0.067	0.085	0.086	0.108
Limiting Creep Strength for Minimum Elongation Rate of 1% in 10000 Hrs.-PSI				
1200°F	8600	14500	14500	14500
1400°F	3200	5600	6400	6000
1600°F	1700	3100	3300	3000
Magnetic Permeability, H=24				
As Cast	1.60	1.04	1.00	1.00
After 2000°F -24 Hrs.-W.Q.	1.83	1.00	1.00	1.00
After 1200°F Creep Test	3.21	1.52	1.23	1.01
After 1400°F Creep Test	3.04	1.39	1.17	1.00
After 1600°F Creep Test	2.90	1.02	1.00	1.03

Thermal Expansion Characteristics

While the coefficients of thermal expansion ordinarily do not differ greatly with small changes in composition, a dilatometer survey of the mid-range heat XJ-130 has been completed. The dilation curves from room temperature to 2000°F appear in Figure 7. The rates of heating and cooling were approximately 10°F per minute. Specimens were in the form of 1/2" wide strips about 1/8" thick, and employed a 4" gauge length. Heating was conducted in a cylindrical furnace of the same design as those employed for creep testing. Expansion was measured by means of a dial gauge connected through fused silica tubes to the specimen. The dilatometer itself was described before the A.S.M.[7] in 1942.

The approximate thermal coefficient of expansion between 1200°F to 1600°F is 0.0000112 in./in./°F; between 80°F and 1600°F it is 0.0000104 in./in./°F. Many engineers prefer a chart that shows the percent expansion after heating from atmospheric to a selected service temperature. For convenience, the thermal expansion data have been converted to this form in Figure 8.

Specifications

Translation of metallurgical research into an industrial specification is desirable. The available data justify the following:

Table 10

Proposed 21%Cr:9%Ni H.R.A. Specifications

	Composition Range						Anticipated Limiting Creep Stress-PSI		
	C%	Mn%	Si%	Cr%	Ni%	N%	1200°F	1400°F	1600°F
A.	.25 / .35	.25 / 1.75	.50 / 1.75	19.0 / 22.0	7.5 / 10.5	.07 / .11	8500 / 14000	3000 / 6400	1600 / 3300
B.	.25 / .35	.25 / 1.75	.50 / 1.00	19.0 / 21.0	8.5 / 10.5	.09 / .11	14500	5500 / 6400	3000 / 3300
C.	.25	1.00	1.75	22.0	7.5	.07	8600	3200	1700

Specification "A" will be easiest to produce and should be satisfactory for non-critical applications below 1600°F.

Specification "B" will confine production to a narrow and relatively high strength range. It may be invoked for critically stressed applications where uniformity of properties is very desirable. Production, which will be difficult, requires careful melting control and exact knowledge of the composition of charge materials. To facilitate production and maintain properties, it is recommended that individual heats outside the limits of "B", but within those of "A", be considered acceptable for critical applications if permeability is below 1.05 as-cast and after water quenching from 24 hours at 2000°F. (See Table 9). Further development of magnetic analysis to serve as an acceptance test for Specification "B" would be desirable.

Appraising ductility and creep strength together, the mid-range heat (XJ-130) appears to possess an optimum combination of the two. This is obviously very desirable as it would be the approximate aim point of production to both specifications A and B.

Specification "C" is suggested for experimental application where considerable ductility over a wide temperature range is required.

Applications

The materials described herein are commercially available as castings. They may be machined and are corrosion resistant. Their carbon content renders them more susceptible to intergranular corrosion and general attack by acids than are the low carbon 18%Cr:8%Ni grades. They are not recommended primarily for corrosion resistance but they are relatively stainless and this property may enhance their value in applications for which they are selected because of other characteristics. The possibility of producing a completely non-magnetic alloy by proper use of the austenite stabilizing balance adapts them to many specialized applications. They have been successfully employed for control levers in tanks, for example, where machinability and non-magnetic qualities coupled with high strength and castability were required.

The alloys are especially recommended for service between 1200°F and 1600°F. In this range, they should become a preferred substitute for 26%Cr:12% Ni steel because of their greater ductility, reduced susceptibility to embrittlement, substantially equivalent creep strength (Figure 9), and lower cost. Their resistance to damage from cyclic heating and cooling has not been established with assurance. The data from the hindered contraction tests suggest that they are superior to the 26%Cr:12%Ni grade(7) in this respect. Figure 10 will serve as a convenient summary of the elevated temperature characteristics of this material.

It is planned to submit a paper on this investigation to the American Society for Metals in the near future.

(signed) Howard S. Avery
Research Metallurgist

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(5) Gow and Harder, "Balancing the Composition of Cast 25%Cr-12%Ni Type Alloys". Transactions A.S.M., December, 1942, Vol. 30, pp. 855-935.

(6) Fellows, Cook and Avery, "Precision in Creep Testing", A.I.M.E. Technical Publication 1443-C, 1942.

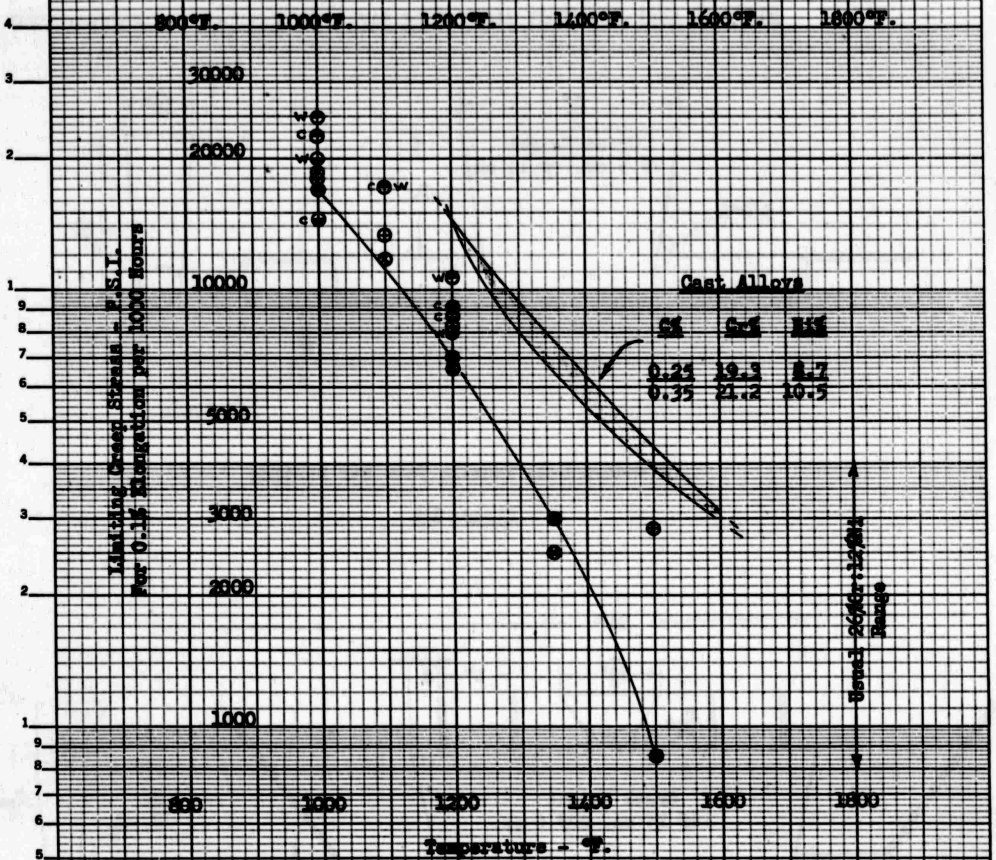
(7) Flinn, Cook, and Fellows, "A Quantitative Study of Austenite Transformation", Transactions A.S.M., March, 1943, Vol. 31, pp. 41-70.

HEAT RESISTANT ALLOYS

18%Cr:8%Ni Type

CR-263-2

EFFECT OF TEMPERATURE ON CREEP STRENGTH



CODE

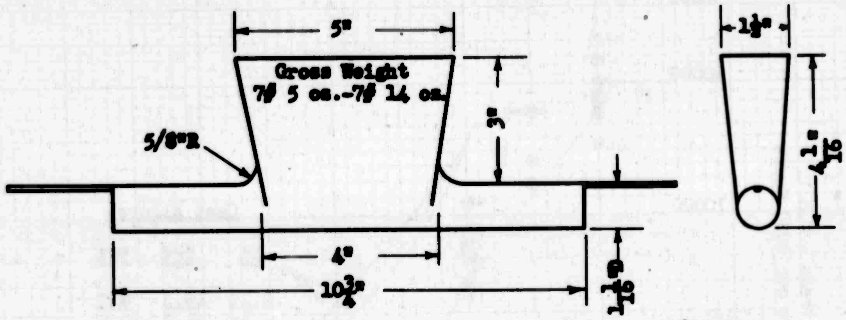
	Type	C%	Mn%	Si%	Ni%	Cr%	Source
●	Wrought	.10	.50mx	.50mx	8/10	17/19	Metal Progress
●	"	.08	2.0mx	.75mx	8/11	18/20	B & W
●		.07	.20/.70	.75mx	8/15	17/19	Timken
c ●	Cast	.07	.50	.65	9.56	18.21	A.S.T.M.
w ●	Wrought	"	"	"	"	"	"
c ●	Cast	.13	.47	.58	9.67	18.50	"
w ●	Wrought	"	"	"	"	"	"

H.S.A.-2/27/45

Figure 1

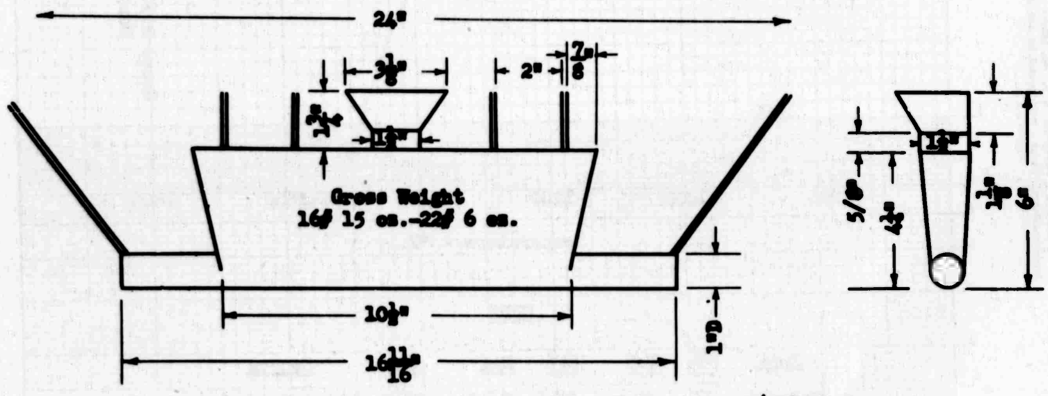
AMERICAN Brake Shoe COMPANY
METALLURGICAL DEPARTMENT

STANDARD HEAT RESISTANT ALLOY CORE SAND TEST CASTINGS RESTRICTED



Standard D-14 Tensile Test Bar Casting

Figure 2A



Standard D-17 Creep Test Bar Casting

RESTRICTED

Figure 2B

Heat No.	C%	Mn%	Si%	Ni%	Cr%	N%
	Chemical Analysis					
XJ131	.34	.92	.48	10.53	19.25	.108

Residual Properties (room temp.) After Creep Testing

Yield Strength P.S.I.	Ult. Tens. Strength P.S.I.	Elong. in 2" %	Red. Area %	Magnetic Permeability H = 24
56250	90000	5.0	8.2	1.030

Plate No. K101102

CT 145

Figure 3
1000X

From creep bar after 1200°F. - 15000 ps.i. for 1001 hours

Etchants:
1:1 HCl + hot alk. K_3FeCy_6

The matrix is austenite containing finely divided carbides. The lamellar structure has not been named or positively identified. It is probably an unusual aggregate of austenite and carbide or nitride. It is apparently fostered by higher nitrogen levels. Its association with ferrite is rare.

Note that this alloy is substantially non-magnetic.

Figure 31 shows this same specimen at lower magnification.

FIGURE 3

Heat No.	C%	Mn%	Si%	Ni%	Cr%	N%
	Chemical Analysis					
XJ129	.25	.96	1.72	7.68	22.33	.067

Residual Properties (room temp.) After Creep Testing

Yield Strength P.S.I.	Ult. Tens. Strength P.S.I.	Elong. in 2" %	Red. Area %	Magnetic Permeability H = 24
57500	88850	15.0	14.1	3.036

Plate No. K13801

CT 104

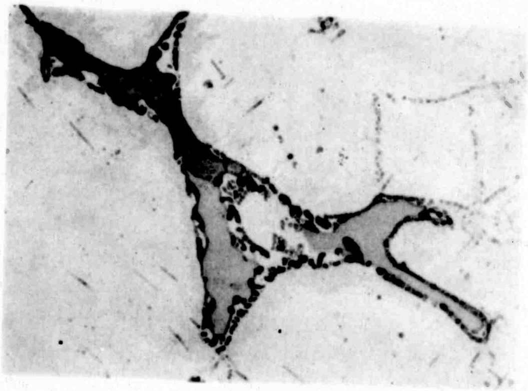


Figure 4
1000X

From creep bar after 1400°F. - 3000 p.s.i. for 1002 hours

Etchants:
1:1 HCl + hot alk. K_3FeCy_6

The matrix is austenite, containing a few scattered particles of carbide and spheroidized chains of carbide that suggest grain boundaries.

The large grey constituents are ferrite and the sigma phase in close association. Transverse cracks, which probably occurred during the room temperature tensile test, characterise the sigma area.

Figure 23 shows this same specimen at lower magnification.

FIGURE 4

Heat No.	C%	Mn%	Si%	Ni%	Cr%	N%
	Chemical Analysis					
XJ129	.25	.96	1.72	7.68	22.33	.067

Residual Properties (room temp.) After Creep Testing

Yield Strength P.S.I.	Ult. Tens. Strength P.S.I.	Elong. in 2" %	Red. Area %	Magnetic Permeability H = 24
65000	92375	20.0	20.2	3.2035

Plate No. K101002

CT 140

Figure 5
1000X

From creep bar after 1200°F. - 10000 p.s.i. for 1004 hours

Etchants:
1:1 HCl + hot alk. K_3FeCy_6

The matrix is austenite with fine precipitated carbides faintly discernible.

The dark mosaic structure is believed to consist chiefly of ferrite, though it probably is associated with some sigma.

Figure 22 shows this same specimen at lower magnification.

FIGURE 5

Heat No.	C%	Mn%	Si%	Ni%	Cr%	N%
	Chemical Analysis					
XK39	.25	.85	.92	8.65	21.20	.085

Residual Properties (room temp.) After Creep Testing

Yield Strength P.S.I.	Ult. Tens. Strength P.S.I.	Elong. in 2" %	Red. Area %	Magnetic Peremability H = 24
50000	100500	16.0	7.4	1.522

Plate No. K101701

CT 159

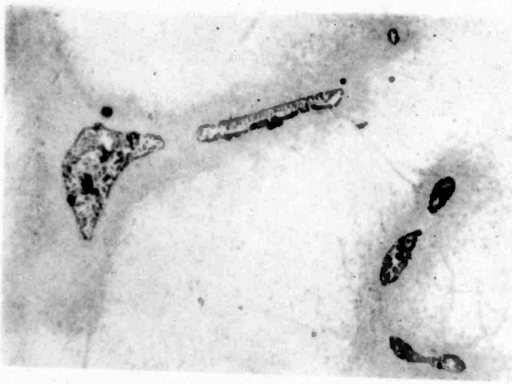


Figure 6
1000X

From creep bar after 1200°F. - 15000 p.s.i. for 1292 hours

Etchants:
1:1 HCl + hot alk. K_3FeCy_6

The matrix is austenite containing fine carbides that were precipitated during the creep test period.

The islands of mosaic structure probably contain ferrite and sigma. Their location, and that of the intensified carbide precipitate are considered to be a reflection of the chemical segregation that occurs in a dendritic pattern and along grain boundaries.

Figure 25 shows the same specimen at lower magnification.

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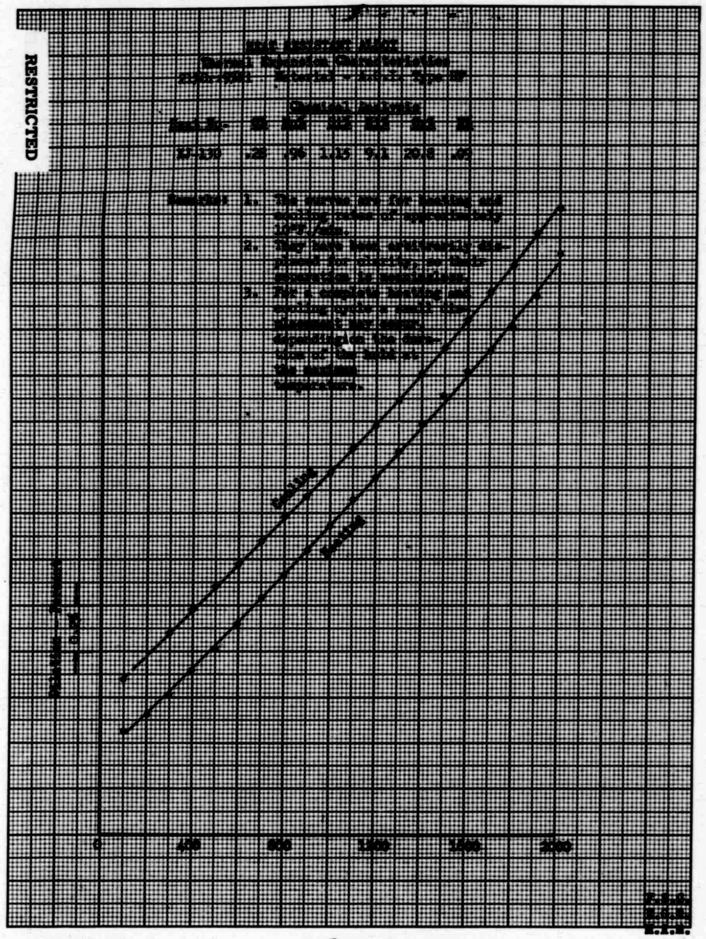

Figure 7

11-8-44

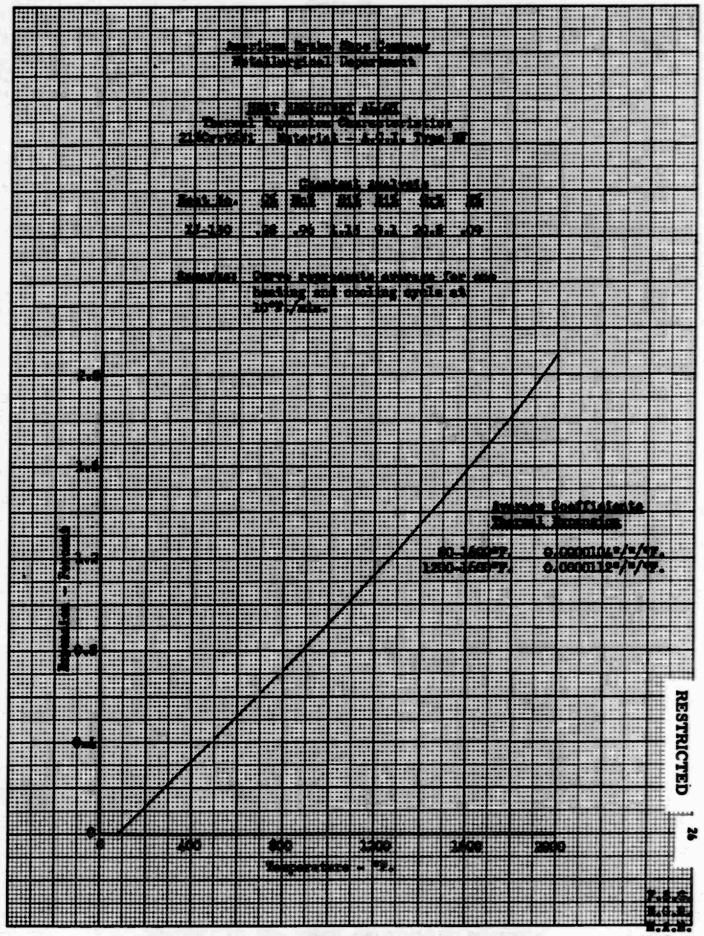

Figure 8

11-8-44

RESTRICTED

RESTRICTED

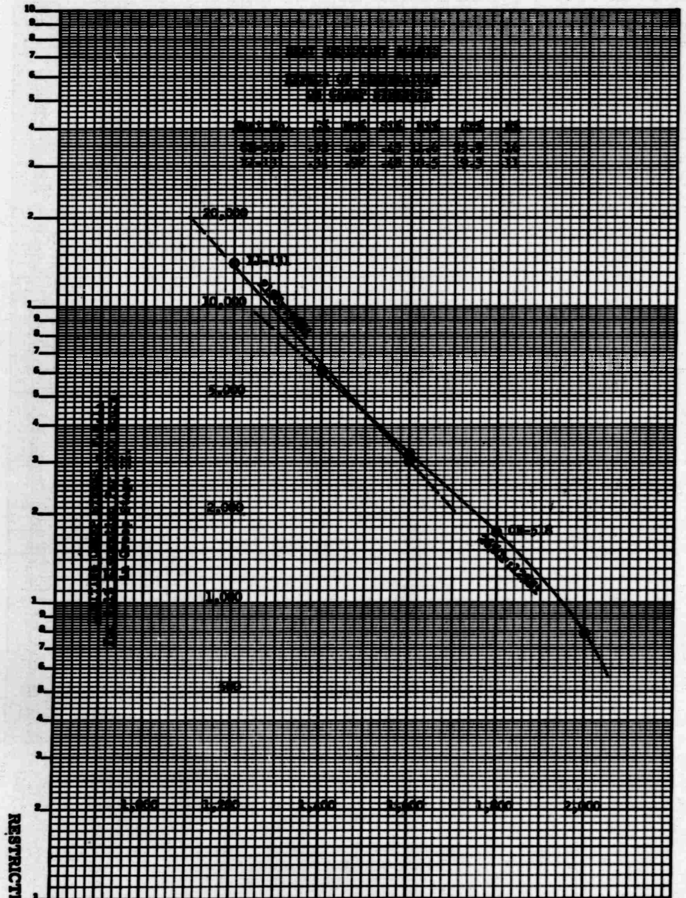

Figure 9

American Brake Shoe Company - Metallurgical Department

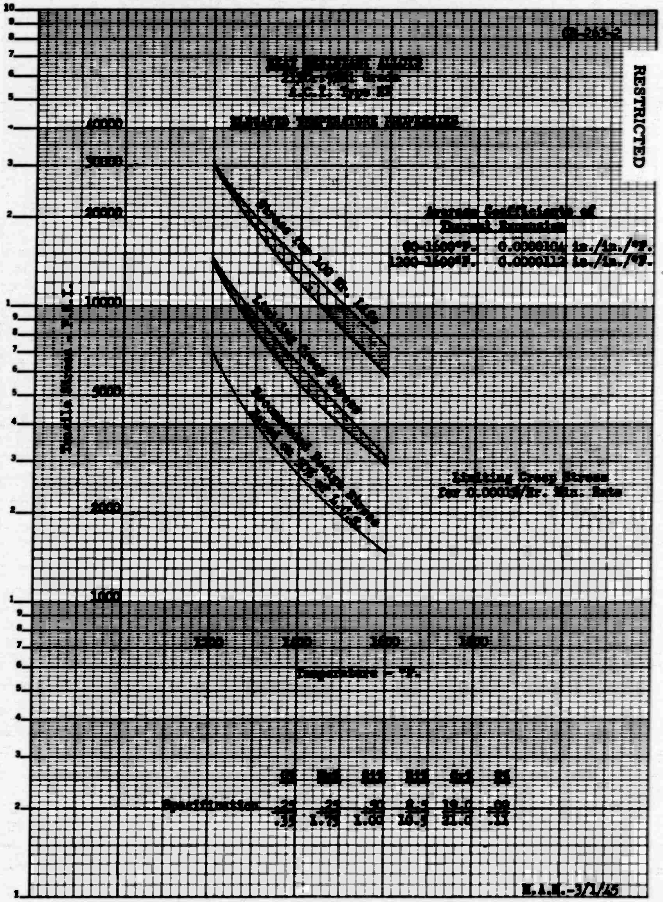

Figure 10

APPENDIX

RESTRICTED

THE AMERICAN BRAKE SHOE AND FOUNDRY CO.

METALLURGICAL DEPARTMENT

TABLE 11

Heat Resistant Alloy Data Sheet
Creep Test Group No. 26D

Heat No.	C%	Mn%	Si%	Ni%	Cr%	N%
CH518	.32	.46	.45	11.5	25.9	.16

Spec. No.	Stress P.S.I.	Creep Characteristics: Duration Hours	Creep Characteristics: Min. Creep Rate % per Hour	Elong. Net %	Residual Prop.-Room Temp.: Tens.Str. P.S.I.	Residual Prop.-Room Temp.: Elong. % 2"	Residual Prop.-Room Temp.: Red.Area %
		2000°F.					
3	500	1511	0.000005	0.2	61600	10.0	11.0
38	1000	1050	0.00045	2.7	48360	2.5	3.5
41A	2000	69.3	0.046	9.0	-	-	-
41B	3000	6.0	0.81	20.0	-	-	-
		1800°F.					
6	1500	1631	0.00003±	0.07	76500	5.0	8.1
39	2000	1140	0.00025±	0.4	73500	7.0	6.6
8	3000	440	0.00251	4.0	-	-	-
9	3000	530	0.00394	6.0	-	-	-
14A	6000	16.6	0.4	12.2	-	-	-
14B	8000	1.7	5.7	21.9	-	-	-
		1600°F.					
36	3000	1640	0.000062	0.2	74000	4.0	4.3
40A	8000	41.4	0.04	4.0	-	-	-
40B	12000	3.2	0.74	4.5	-	-	-
		1400°F.					
37	6000	1150	0.000112	0.2	70500	3.0	5.4
35	8000	1070	0.00047	1.0	-	-	-
15A	15000	60.3	0.038	3.0	-	-	-
15B	20000	13.9	0.26	5.5	-	-	-
11B	25000	2.5	1.99	7.8	-	-	-
		70°F.					
13B	As Cast				82000	15.5	23.7

H.S.A. - 9/25/40

AMERICAN BRAKE SHOE COMPANY

METALLURGICAL DEPARTMENT

Mahwah, N. J. February 6, 1945

Table 12

STRESS-STRAIN-RUPTURE AND CREEP TEST COMPARISONS
21%Cr:9%Ni Alloys at 1200°F. C-263

Heat No.:	XJ-129	XK-39	XJ-130	XJ-131
	Chemical Analysis			
C%	.25	.25	.28	.34
Mn%	.96	.85	.96	.92
Si%	1.72	.92	1.15	.48
Ni%	7.68	8.65	9.10	10.53
Cr%	22.33	21.20	20.80	19.25
N%	.067	.085	.086	.108
Tested at 1200°F. and 45000 P.S.I.				
Life - Hrs.	-	-	1.28	.62
Min. Creep Rate - % per Hr.	-	-	.40	1.45
Total Elongation - %	-	-	11.5	10.0
Red. Area - %	-	-	13.8	17.0
Tested at 1200°F. and 35000 P.S.I.				
Life - Hrs.	2.83	25.4	19.07	14.18
Min. Creep Rate - % per Hr.	3.98	.048	.057	.033
Elongation - %	22.0	9.0	5.0	5.5
Red. Area - %	23.0	11.1	6.7	5.5
Tested at 1200°F. and 25000 P.S.I.				
Life - Hrs.	64.08	-	-	-
Min. Creep Rate - % per Hr.	.25	-	-	-
Total Elongation - %	22.0	-	-	-
Red. Area - %	21.4	-	-	-
Tested at 1200°F. and 15000 P.S.I.				
Life - Hrs.	-	1292.(d)	1004.(d)	1001.(d)
Min. Creep Rate - % per Hr.	-	.000133	.000131	.000123
Total Elongation - %	-	-	-	-
Red. Area - %	-	-	-	-
Tested at 1200°F. and 10000 P.S.I.				
Life - Hrs.	1004.(d)	-	-	-
Min. Creep Rate - % per Hr.	.000288	-	-	-
Total Elongation - %	-	-	-	-
Red. Area - %	-	-	-	-

(d) discontinued before fracture

M.A.M-2/6/45

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AMERICAN BRAKE SHOE COMPANY

METALLURGICAL DEPARTMENT

Mahwah, N. J. February 5, 1945

G-263

Table 13

STRESS-STRAIN-RUPTURE AND CREEP TEST COMPARISONS
21%Cr:9%Ni Alloys at 1400°F.

Heat No.:	XY-129	XX-39	XY-130	XY-131
	Chemical Analysis			
C%	.25	.25	.28	.34
Mn%	.96	.85	.96	.92
Si%	1.72	.92	1.15	.48
Ni%	7.68	8.65	9.10	10.53
Cr%	22.33	21.20	20.80	19.25
N%	.067	.085	.086	.108
Tested at 1400°F. and 20000 P.S.I.				
Life - Hrs.	3.52	6.15	7.8	6.43
Min. Creep Rate - % per Hr.	5.6	.78	.46	.33
Total Elongation - %	44.0	10.0	5.5	3.5
Red. Area - %	46.3	15.2	7.7	6.2
Tested at 1400°F. and 15000 P.S.I.				
Life - Hrs.	20.0	37.37	63.88	29.75
Min. Creep Rate - % per Hr.	1.3	.13	.053	.042
Total Elongation - %	49.0	9.0	6.0	2.5
Red. Area - %	51.9	13.4	6.2	7.3
Tested at 1400°F. and 6000 P.S.I.				
Life - Hrs.	-	1004.(d)	1009.(d)	1005.(d)
Min. Creep Rate - % per Hr.	-	.00016	.000062	.000096
Total Elongation - %	-	-	-	-
Red. Area - %	-	-	-	-
Tested at 1400°F. and 3000 P.S.I.				
Life - Hrs.	1002.(d)	-	-	-
Min. Creep Rate - % per Hr.	.000082	-	-	-
Total Elongation - %	-	-	-	-
Red. Area - %	-	-	-	-

(d) discontinued before fracture.

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H.A.M.-2/6/45

AMERICAN BRAKE SHOE COMPANY

METALLURGICAL DEPARTMENT

Mahwah, N. J. February 6, 1945

Table 14

STRESS-STRAIN-RUPTURE AND CREEP TEST COMPARISONS
21%Cr:9%Ni Alloys at 1600°F.

G-263

Heat No.:	XY-129	XX-39	XY-130	XY-131
	Chemical Analysis			
C%	.25	.25	.28	.34
Mn%	.96	.85	.96	.92
Si%	1.72	.92	1.15	.48
Ni%	7.68	8.65	9.10	10.53
Cr%	22.33	21.20	20.80	19.25
N%	.067	.085	.086	.108
Tested at 1600°F. and 12000 P.S.I.				
Life - Hrs.	-	-	2.82	5.48
Min. Creep Rate - % per Hr.	-	-	2.34	.587
Total Elongation - %	-	-	21.0	7.0
Red. Area - %	-	-	23.7	9.2
Tested at 1600°F. and 10000 P.S.I.				
Life - Hrs.	4.0	5.35	-	-
Min. Creep Rate - % per Hr.	6.8	2.09	-	-
Total Elongation - %	50.0	15.0	-	-
Red. Area - %	48.4	20.2	-	-
Tested at 1600°F. and 8000 P.S.I.				
Life - Hrs.	-	17.63	45.99	32.50
Min. Creep Rate - % per Hr.	-	.36	.069	.118
Total Elongation - %	-	10.0	7.0	13.0
Red. Area - %	-	18.8	8.5	11.1
Tested at 1600°F. and 7000 P.S.I.				
Life - Hrs.	35.62	-	-	-
Min. Creep Rate - % per Hr.	.63	-	-	-
Total Elongation - %	42.5	-	-	-
Red. Area - %	41.3	-	-	-
Tested at 1600°F. and 3000 P.S.I.				
Life - Hrs.	-	1003 (d)	1003 (d)	1081 (d)
Min. Creep Rate - % per Hr.	-	.0000814	.000046	.000096
Total Elongation - %	-	-	-	-
Red. Area - %	-	-	-	-
Tested at 1600°F. and 1500 P.S.I.				
Life - Hrs.	1004 (d)	-	-	-
Min. Creep Rate - % per Hr.	.000051	-	-	-
Total Elongation - %	-	-	-	-
Red. Area - %	-	-	-	-

(d) discontinued before fracture.

RESTRICTED

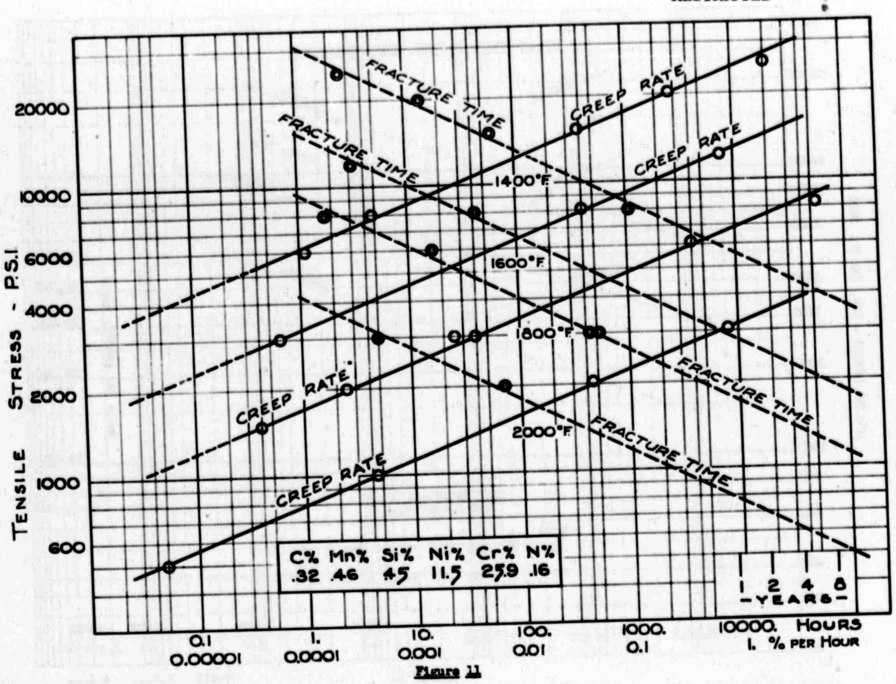


Figure 11

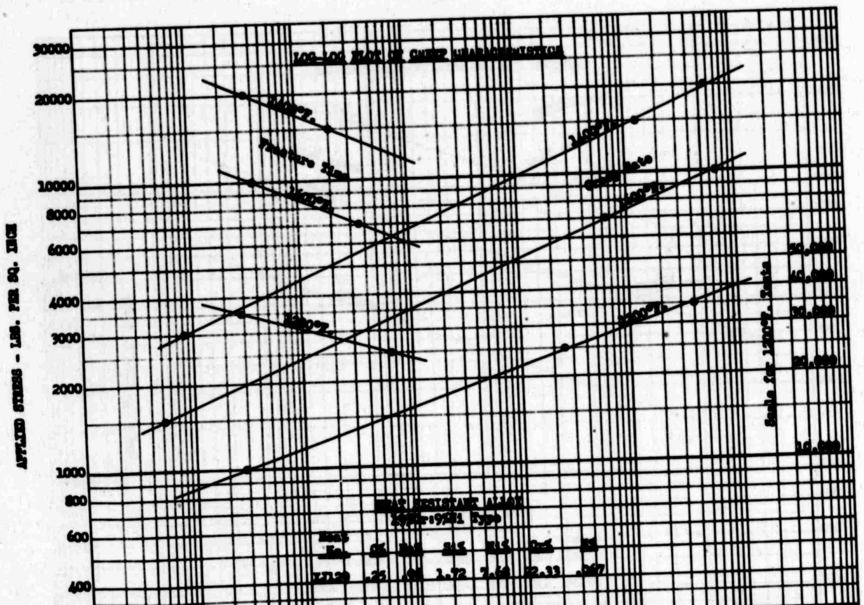


Figure 12

6-263 F.S.G. 9-6-44

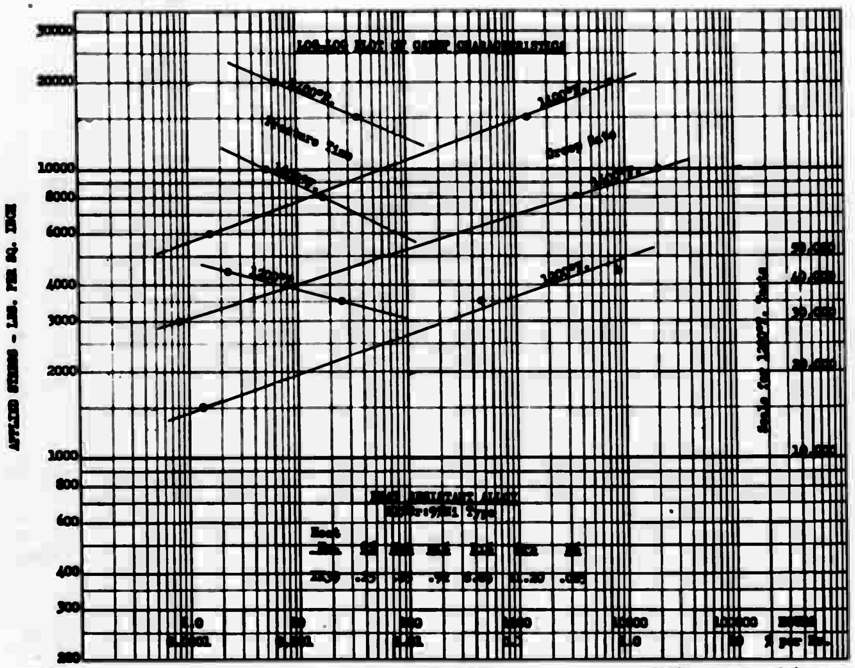


Figure 13 G-263 F.S.G. 9-6-44

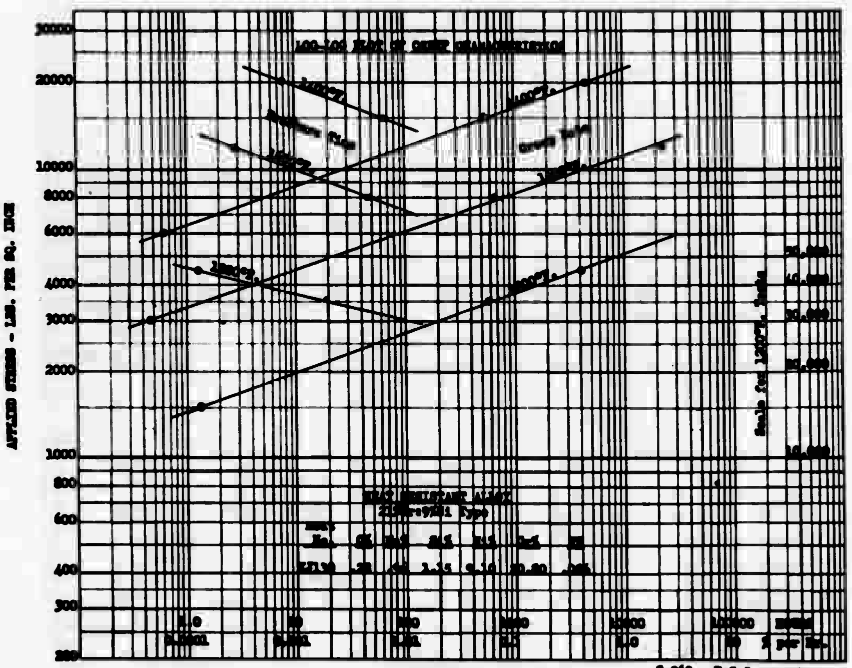


Figure 14 G-263 F.S.G. 9-6-44

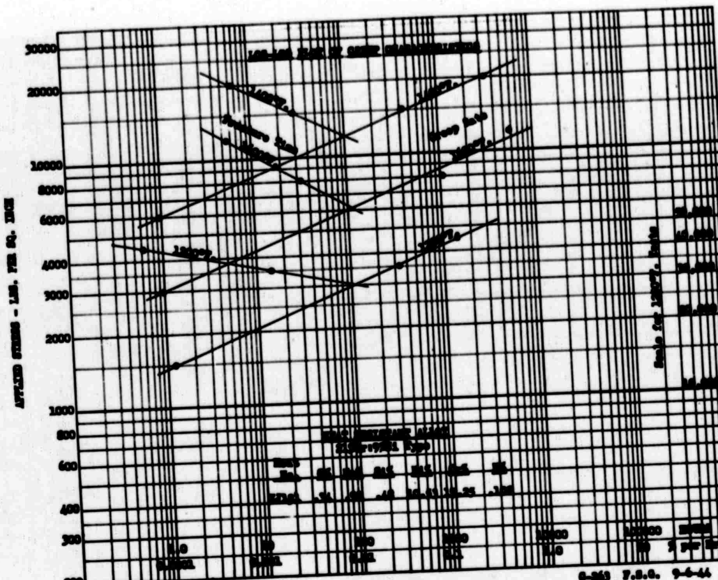


Figure 15

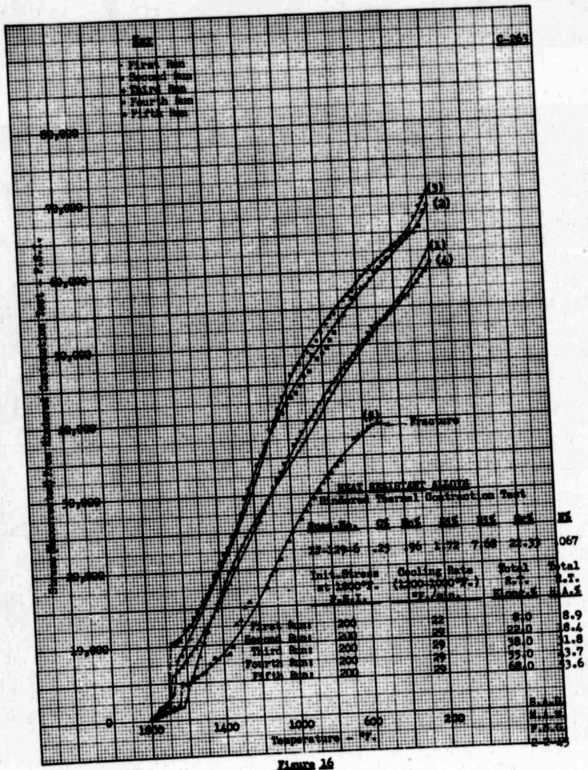


Figure 16

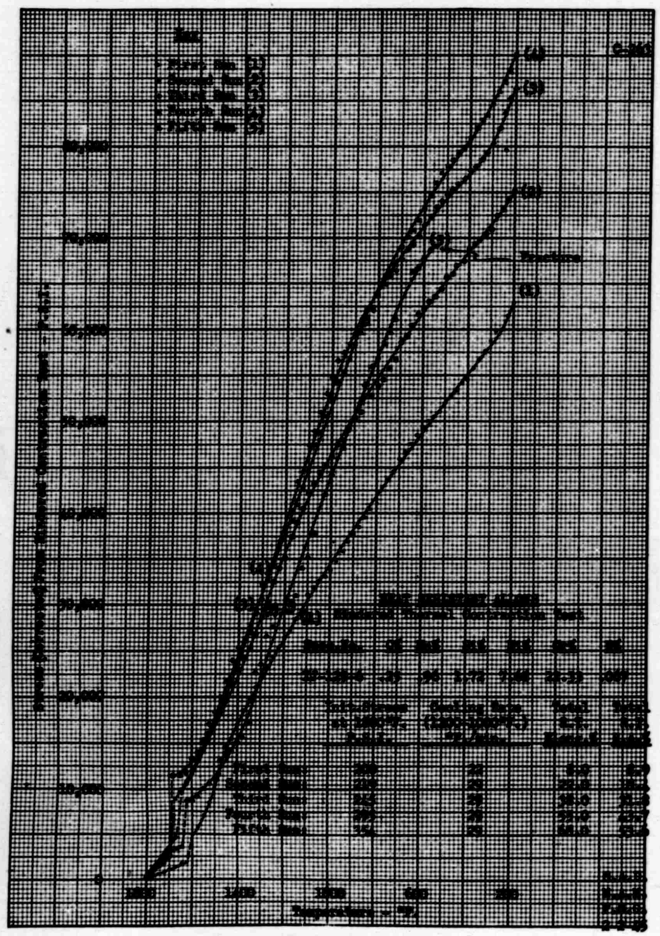


Figure 17

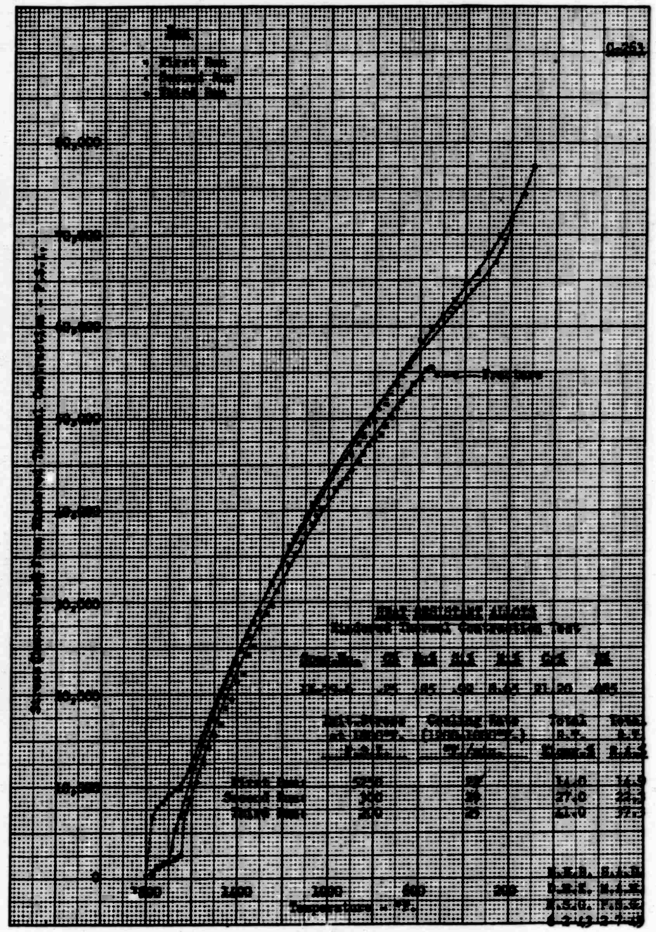


Figure 18

RESTRICTED

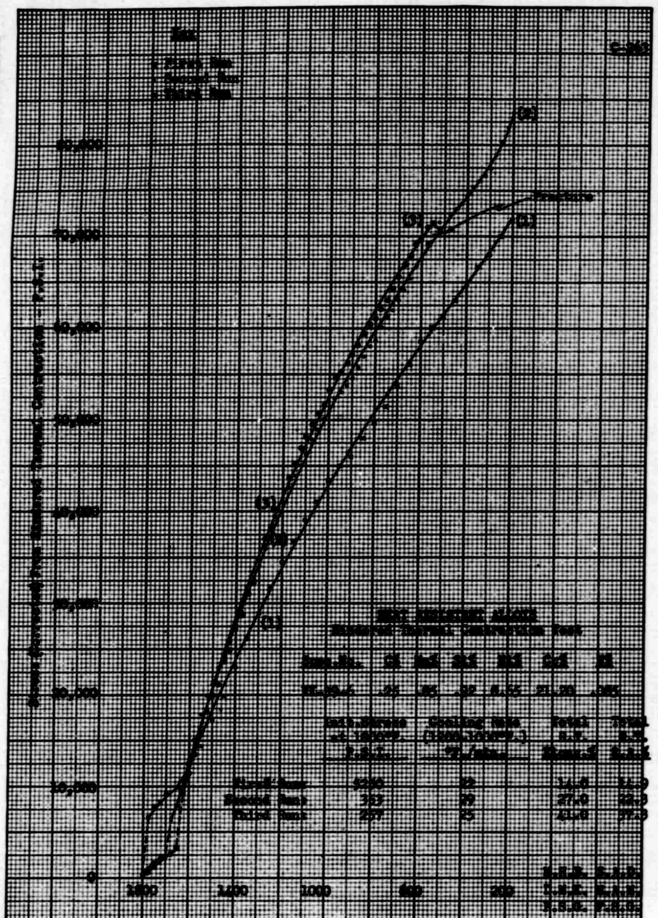


Figure 19

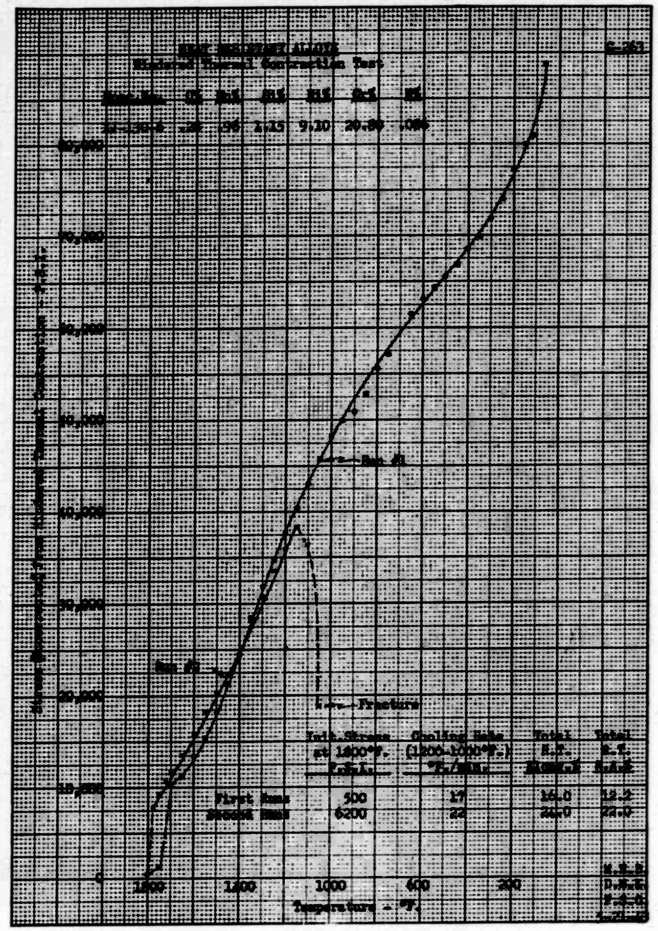


Figure 20

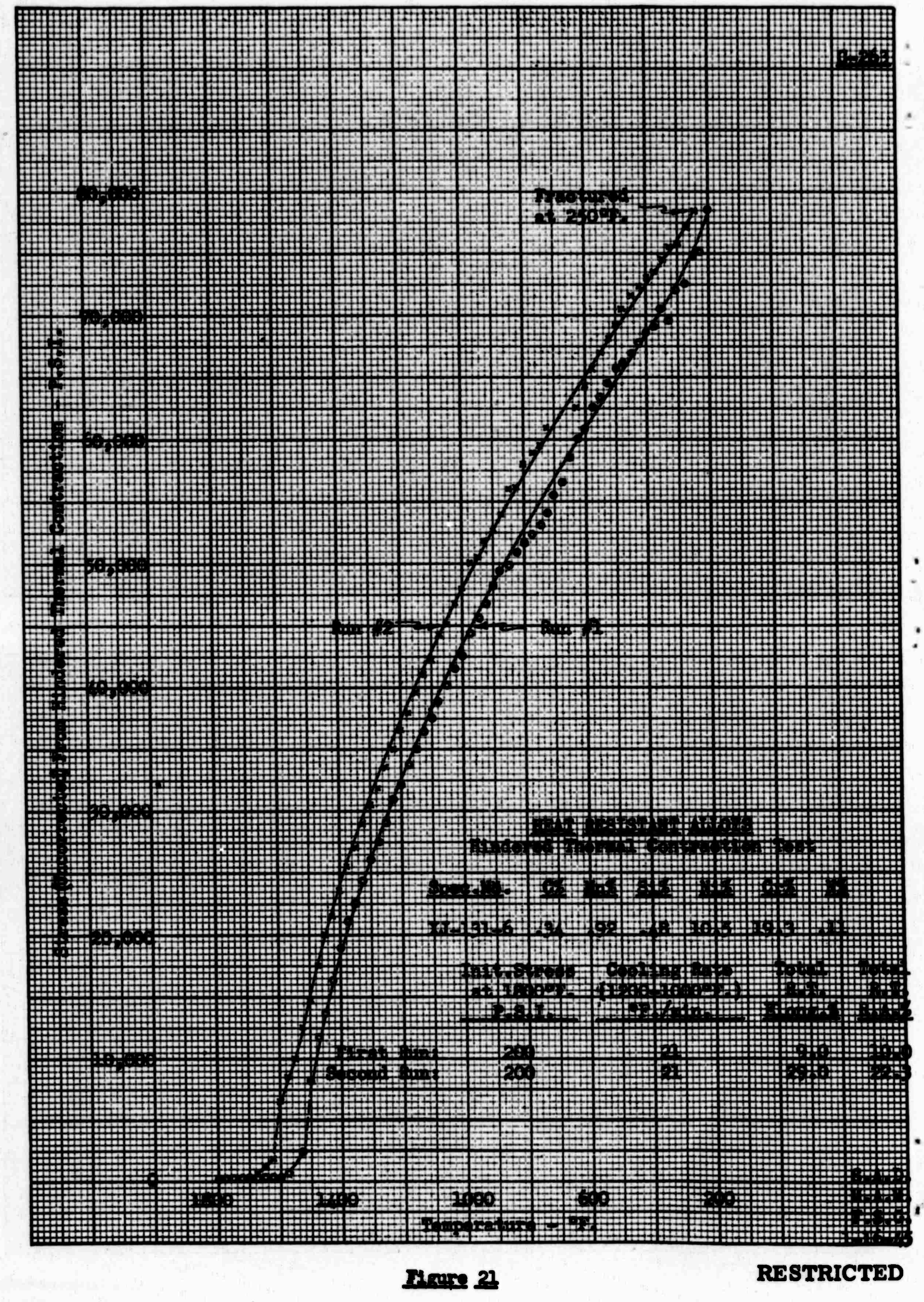

Fractured at 250°F.
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Run #2
Run #1
HEAT RESISTANT ALLOYS
Hindered Thermal Contraction Test
First Run:
Second Run:
200
21
1800
1400
1000
600
200
Temperature - °F.

Figure 21

Plate No. K101001

CT 140

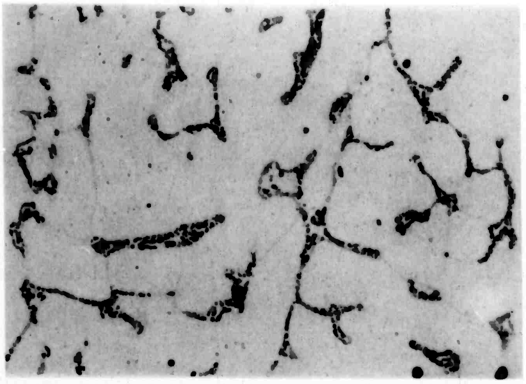


Figure 22
250X

From creep bar after 1200°F. - 10000 p.s.i. for 1004 hours

Plate No. K13804

CT 104

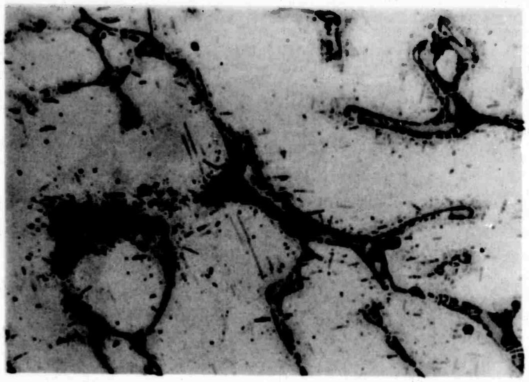


Figure 23
250X

From creep bar after 1400°F. - 3000 p.s.i. for 1002 hours

Plate No. K13901

CT 112

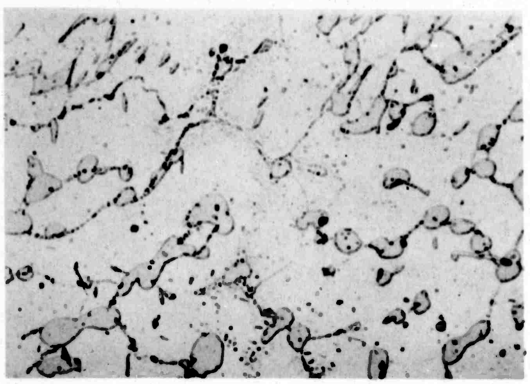


Figure 24
250X

From creep bar after 1600°F. - 1500 p.s.i. for 1004 hours

Heat	Chemical Analysis					
No.	C%	Mn%	Si%	Ni%	Cr%	N%
KJ129	.25	.96	1.72	7.68	22.33	.067

Etchants: 1:1 HCl + hot alk. K_3FeCy_6 (10%)

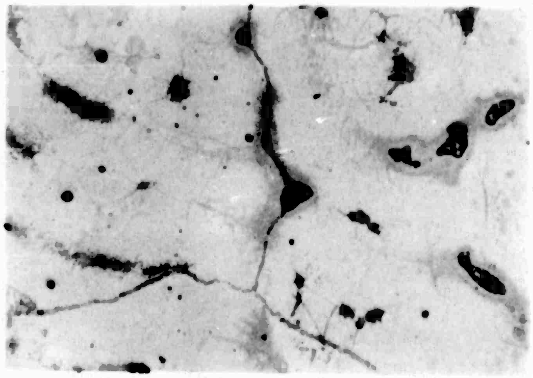


Plate No. K101702

CT 159

Figure 25
250X

From creep bar after 1200°F. - 15000 p.s.i. for 1292 hours

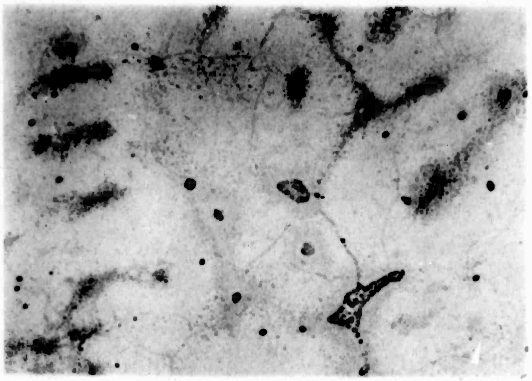


Plate No. K101201

CT 152

Figure 26
250X

From creep bar after 1400°F. - 6000 p.s.i. for 1004 hours

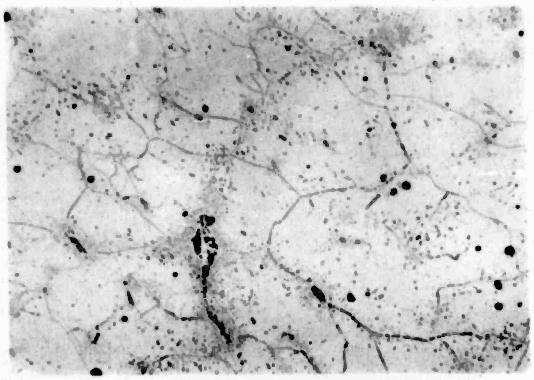


Plate No. K100801

CT 127

Figure 27
250X

From creep bar after 1600°F. - 3000 p.s.i. for 1003 hours

Heat No.	Chemical Analysis C%	Mn%	Si%	Ni%	Cr%	N%
XK39	.25	.85	.92	8.65	21.20	.085

Etchants: 1:1 HCl + hot alk. K_3FeCy_6 (10%)

Plate
No.
K100901

CT
135

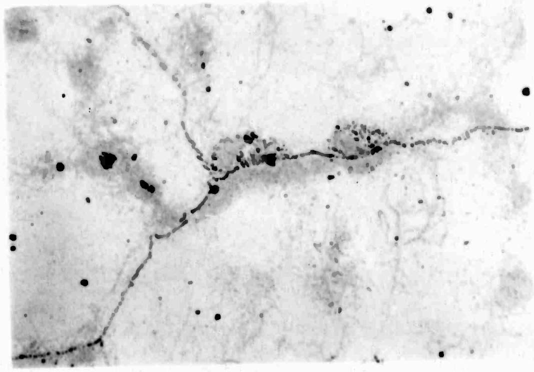


Figure 28
250X

From creep bar after
1200°F. - 15000 p.s.i.
for 1004 hours

Plate
No.
K14002

CT
106

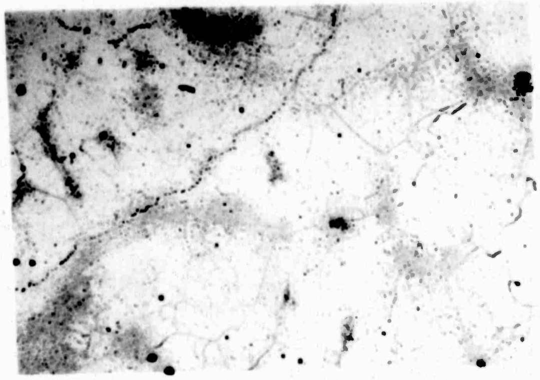


Figure 29
250X

From creep bar after
1400°F. - 6000 p.s.i.
for 1003 hours

Plate
No.
K100701

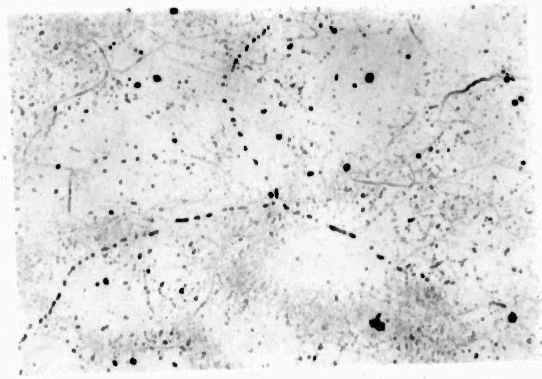


Figure 30
250X

From creep bar after
1600°F. - 3000 p.s.i.
for 1003 hours

Heat No.	Chemical Analysis C%	Mn%	Si%	Ni%	Cr%	N%
XJ130	.28	.96	1.15	9.10	20.80	.086

Etchants: 1:1 HCl + hot alk. K_3FeCy_6 (10%)

Plate No. 101101

CT 145

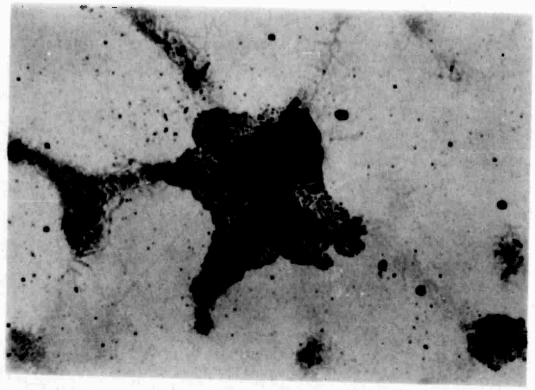


Figure 31
250X

From creep bar after 1200°F. - 1500 p.s.i. for 1001 hours

Plate No. K14102

CT 105

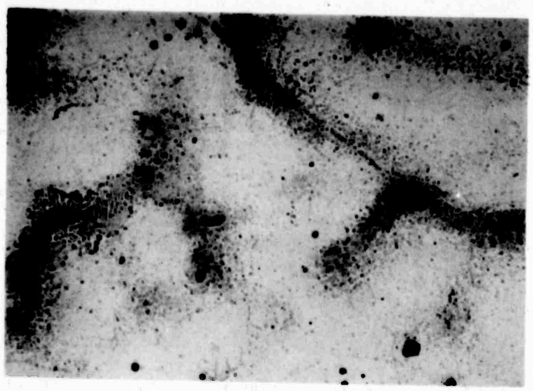


Figure 32
250X

From creep bar after 1400°F. - 6000 p.s.i. for 1005 hours

Plate No. K14201

CT 110

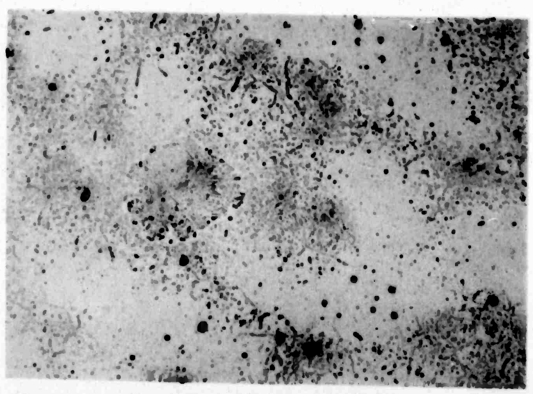


Figure 33
250X

From creep bar after 1600°F. - 3000 p.s.i. for 1001 hours

Heat No.	Chemical Analysis C%	Mn%	Si%	Ni%	Cr%	N%
XJ131	.34	.92	.48	10.53	19.25	.108

Etchants: 1:1 HCl + hot alk. K_3FeCy_6 (10%)

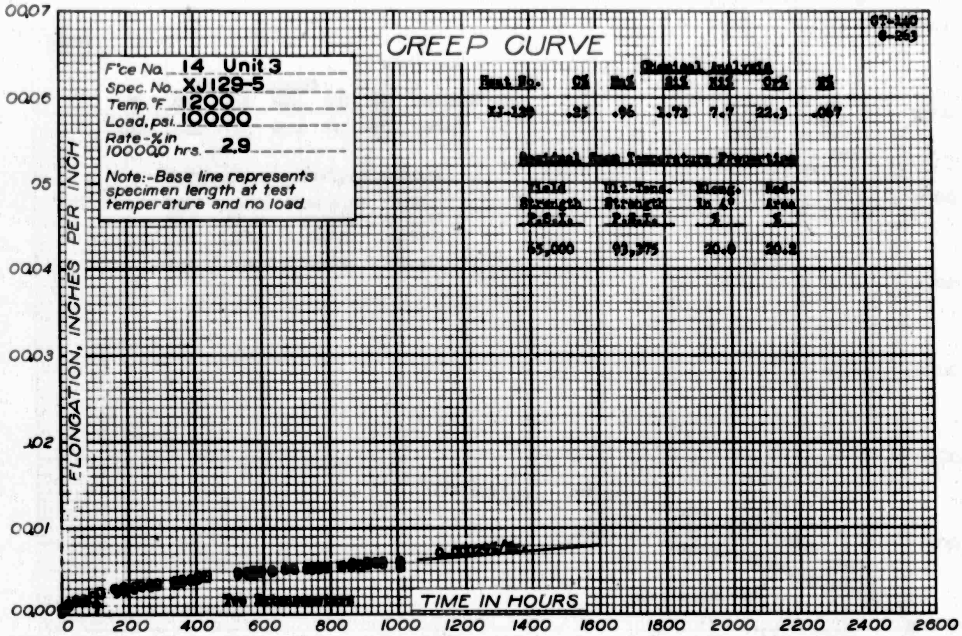


Figure 34

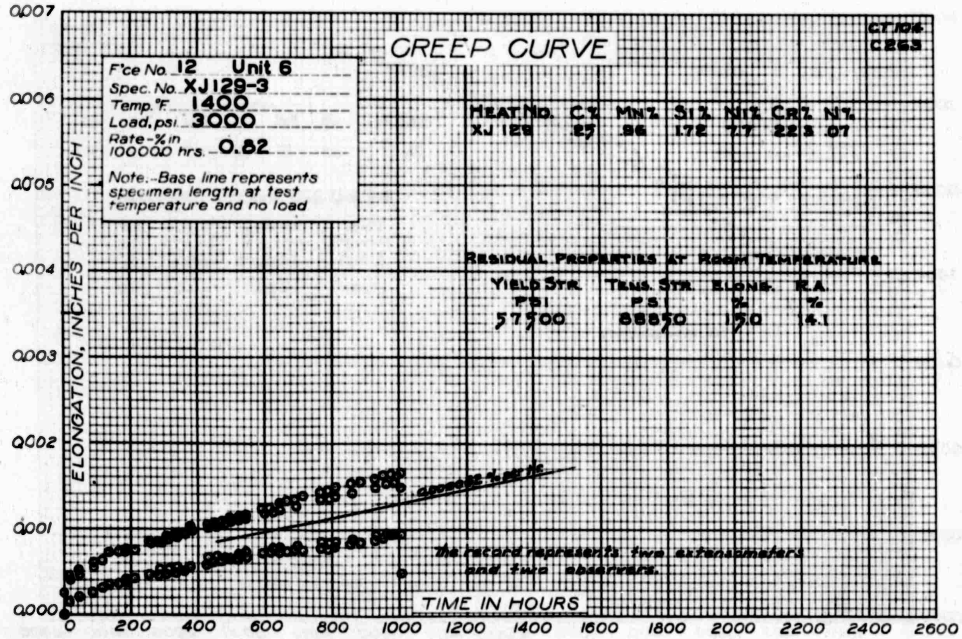
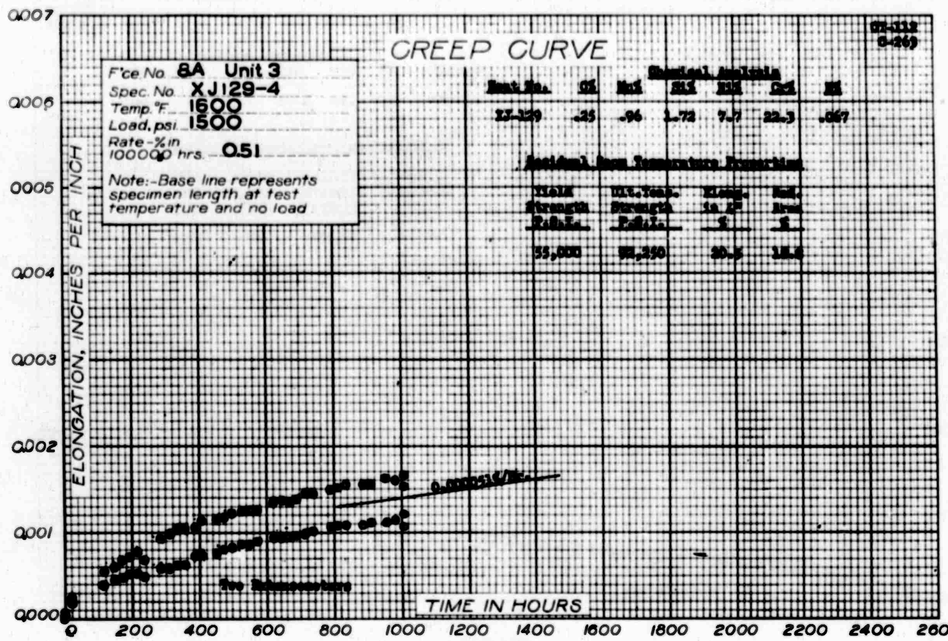
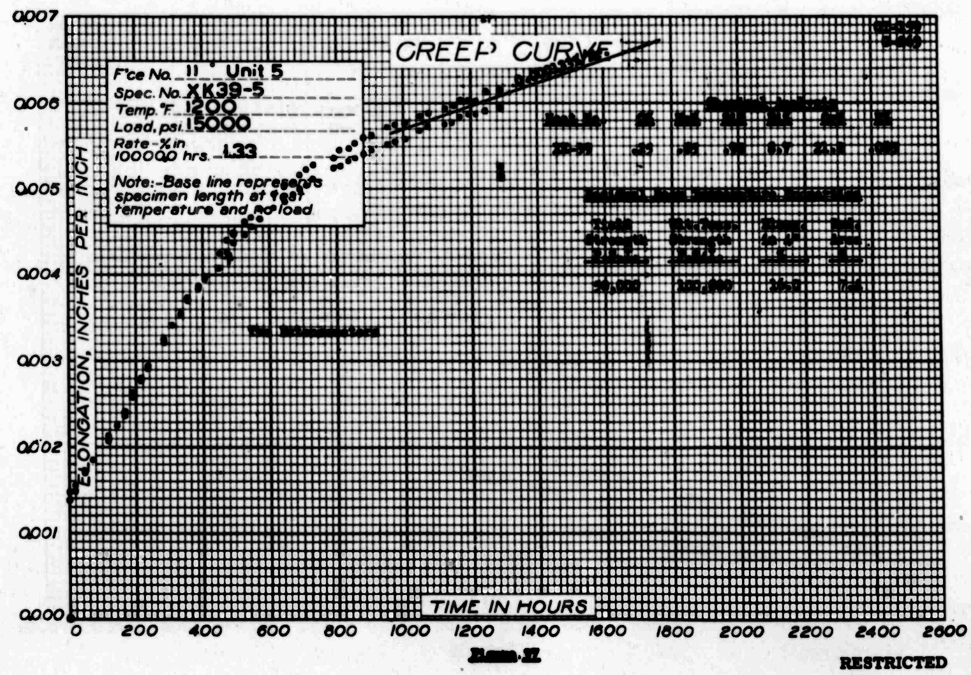


Figure 35


CREEP CURVE
F'ce No. 8A Unit 3
Spec. No. XJ129-4
Temp. °F. 1600
Load, psi 1500
Rate-% in 10000.0 hrs. 0.51
Note:-Base line represents specimen length at test temperature and no load
ELONGATION, INCHES PER INCH
TIME IN HOURS
0.000
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600

[illegible]


CREEP CURVE
F'ce No. 11 Unit 5
Spec. No. XK39-5
Temp. °F. 1200
Load, psi 15000
Rate-% in 10000.0 hrs. 1.33
Note:-Base line represents specimen length at test temperature and no load
ELONGATION, INCHES PER INCH
TIME IN HOURS
0.000
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600

[illegible]

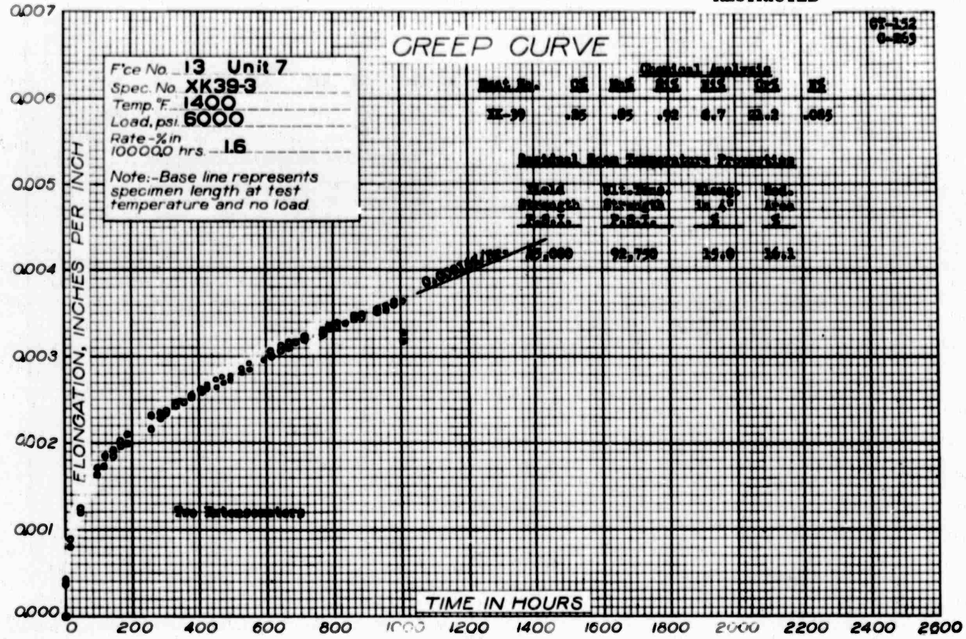


Figure [illegible]

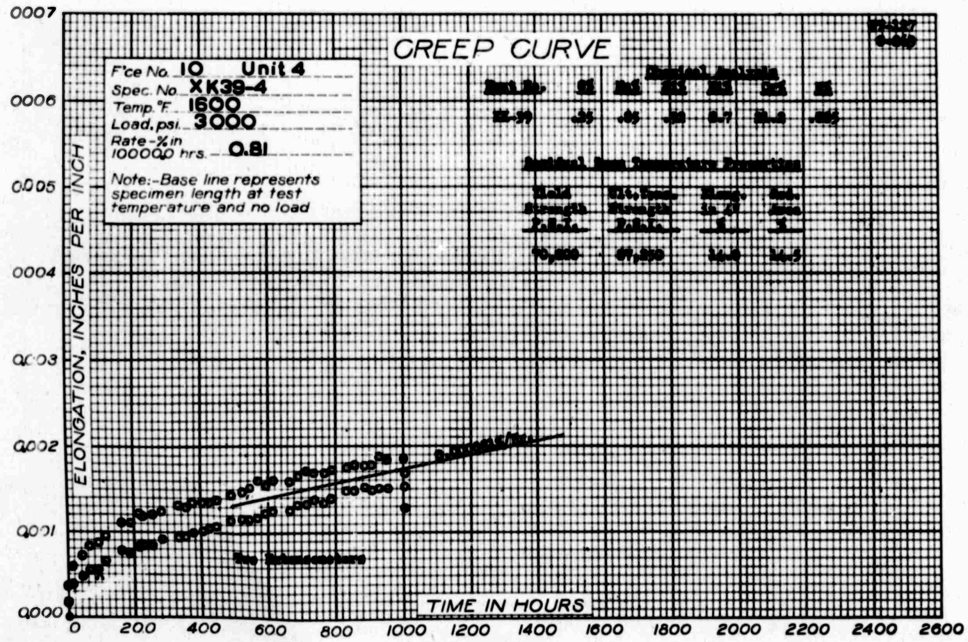


Figure [illegible]

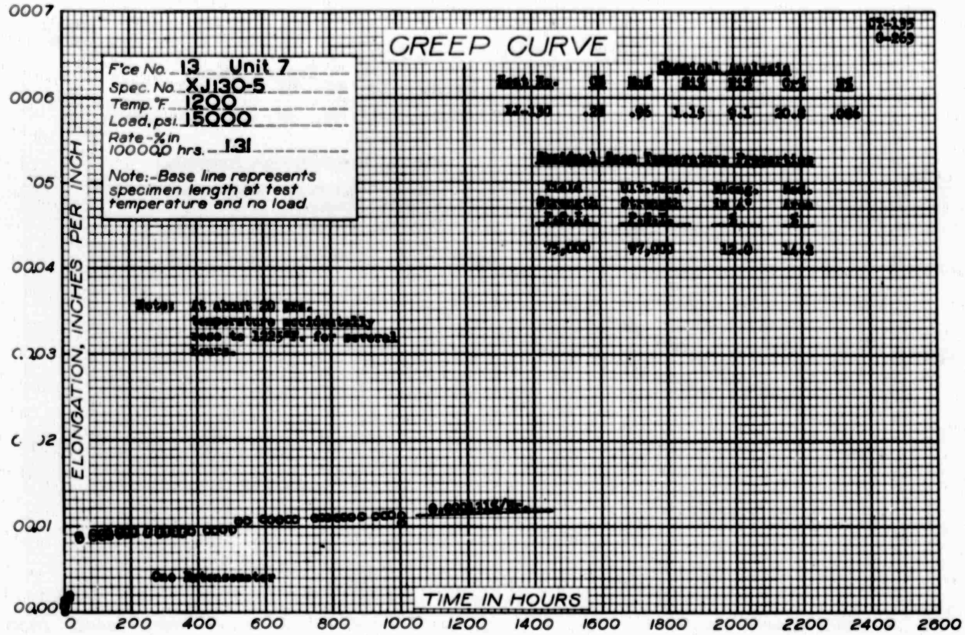


Figure 10

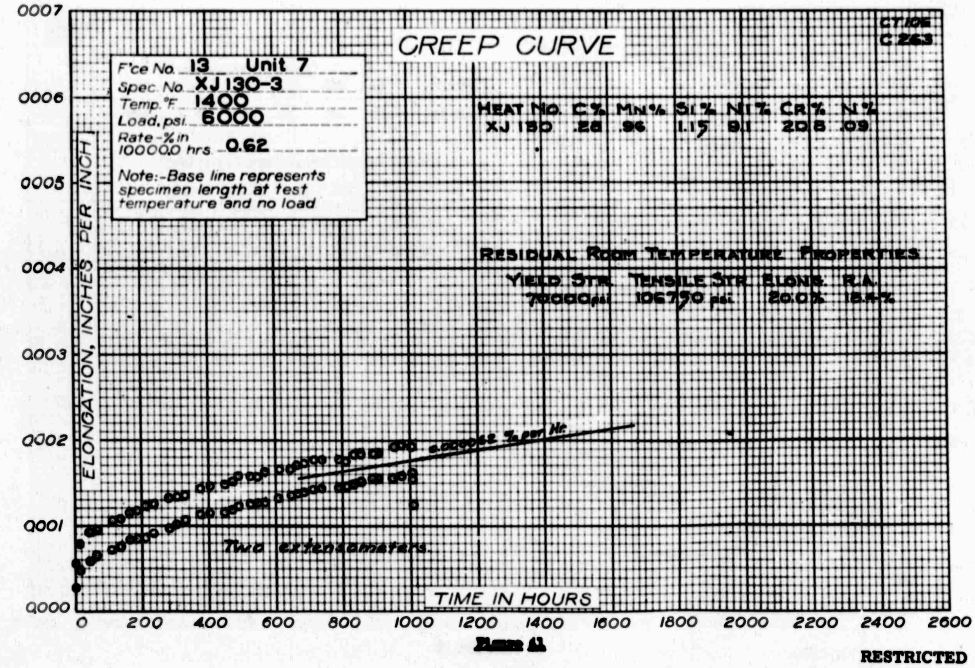


Figure 11

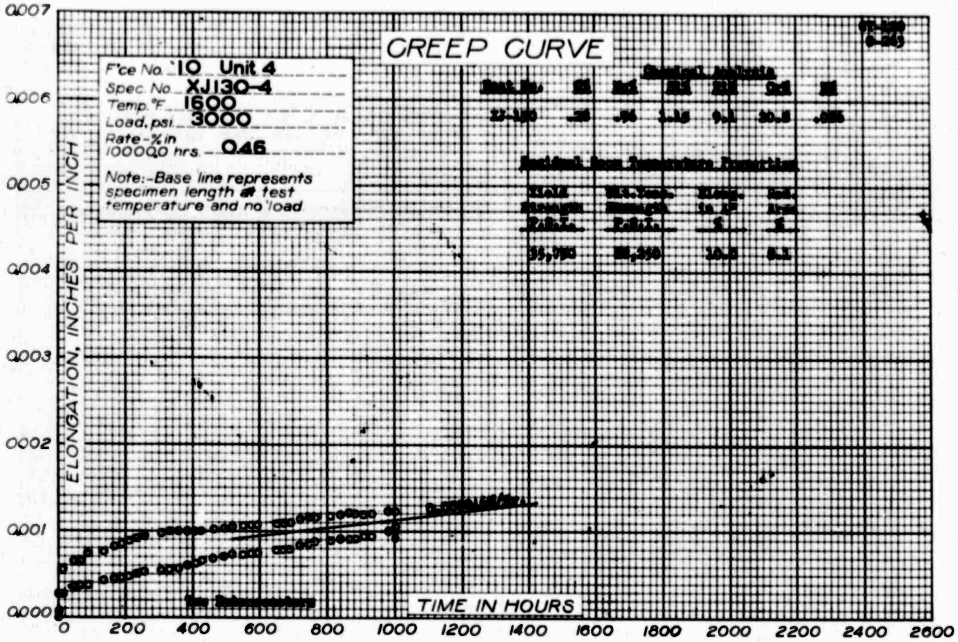


Figure 42

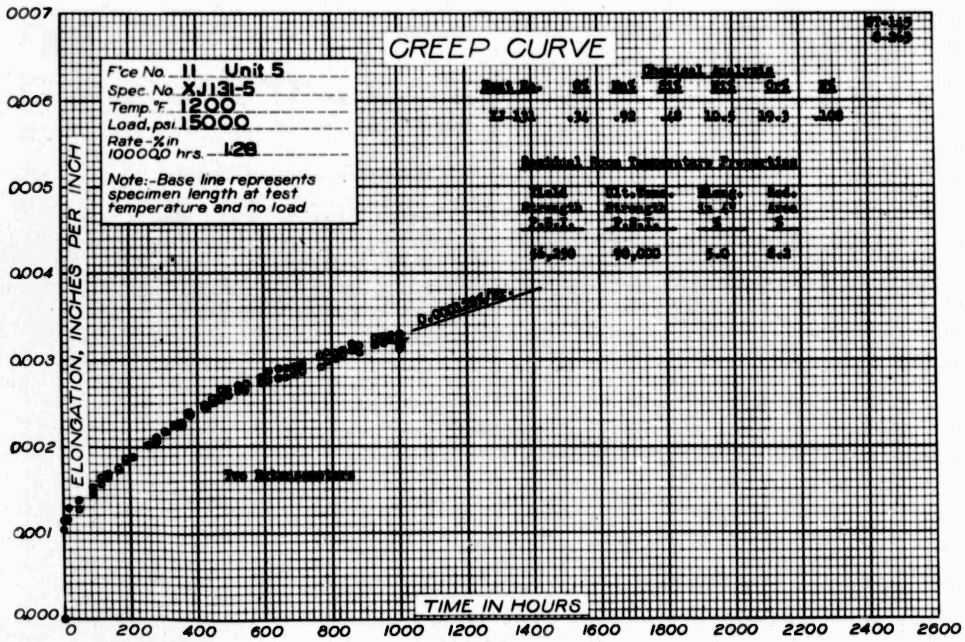


Figure 43

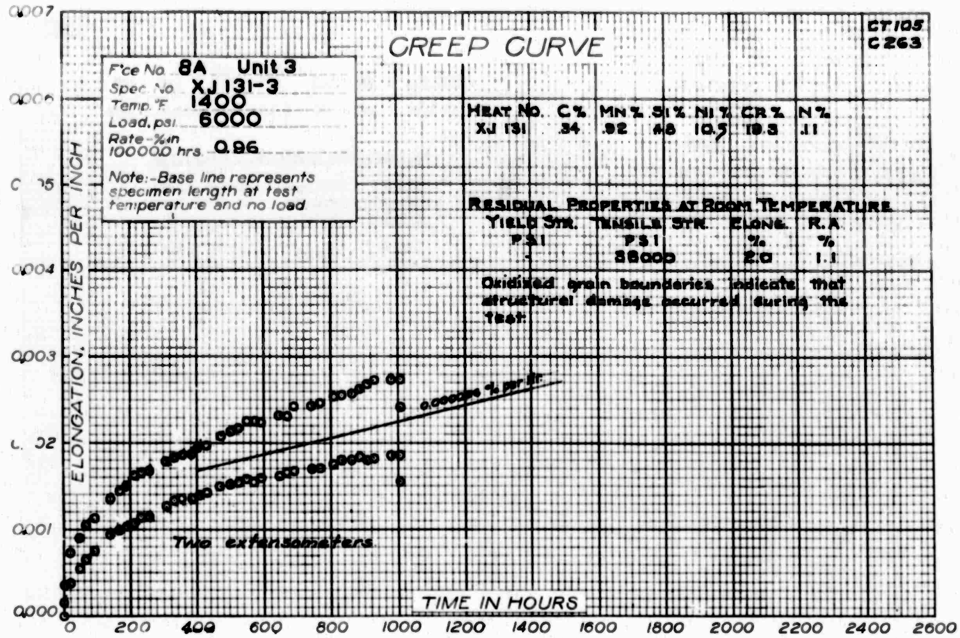


Figure 44

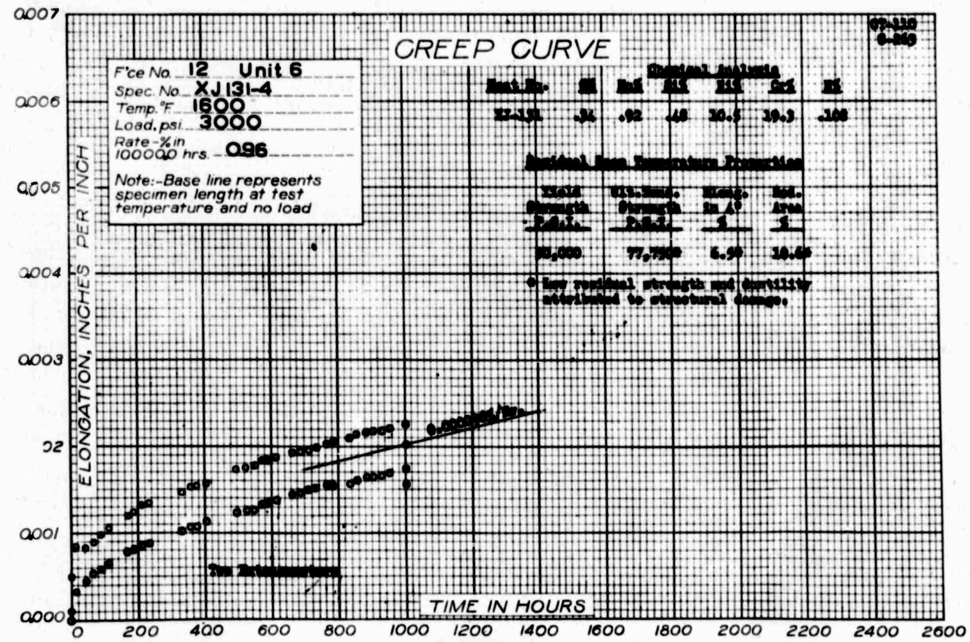


Figure 45

RFEL – C

1085

A.T.I.

28110

TITLE: Heat-Resistant Alloys for Ordnance Materiel and Aircraft and Naval Engine Parts (N-102): Part I - Heat-Resistant Alloys of The 21 percent Cr. 9 percent Ni Type

AUTHOR(S): Avery, H. S.; Cook, E.

ORIGINATING AGENCY: American Brake Shoe Co., Mahwah, N. J.

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ABSTRACT:

Investigations were made to determine the elevated-temperature characteristics of heat-resisting alloys such as 18%Cr: 8%Ni stainless steel. To improve oxidation resistance, the Cr level of 18:8 was raised to 19-22%, and to provide austenite stabilization, the nickel range was set at 8.5-10.5% and 0.07-0.11% N included. Compositions of this type are quite strong and ductile at 1800°F, and may become brittle in the range from 1200°- 1600°F. It was found that 21%Cr: 9%Ni grade may be substituted for 26%Cr:12%Ni up to a temperature of 1600°F with change of design stress. The chief value of this material is in the heat-resistant alloy field, but it is also suitable for applications that require a strong, tough, machinable, noncorrosive and nonmagnetic metal.

P11/4

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DIVISION: Materials ~~(8)~~ 8 14

SECTION: General Data ~~(15)~~ 6

SUBJECT HEADINGS: High temperature alloys (49326); Alloys - Corrosion prevention (10270)

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